AD-A125 998 REMR (REPAIR EVALUATION MAINTENANCE AND REHABILITATION) 1/4
RESEARCH PROGRAM DEVELOPMENT REPORT(U) ARMY ENGINEER
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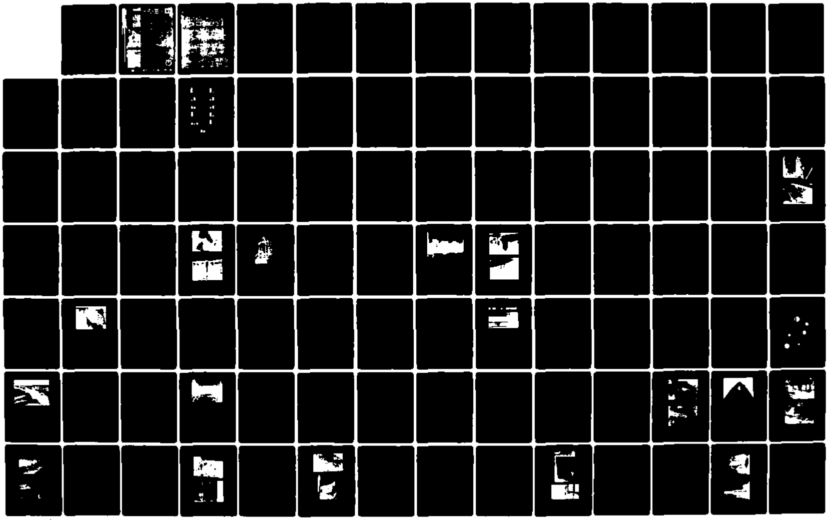

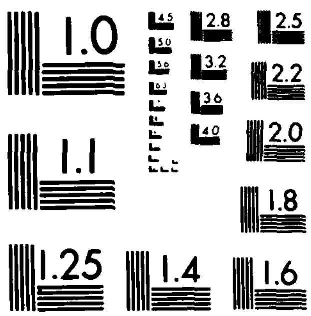

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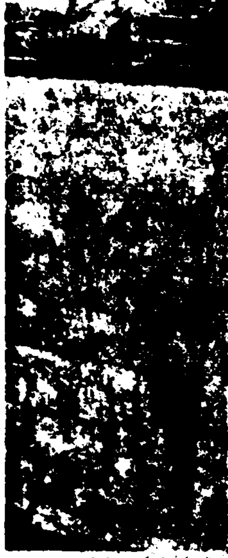

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REPAIR, EVALUATION, MAINTENANCE, AND REHABILITATION RESEARCH PROGRAM

REMR RESEARCH PROGRAM DEVELOPMENT REPORT

By

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U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

February 1983

Final Report

83 03 23 017

Prepared for

Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A125 998	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) REMR Research Program Development Report		5. TYPE OF REPORT & PERIOD COVERED Final report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) John M. Scanlon, Jr.; James E. McDonald; Clifford L. McAnear; E. Dale Hart; Robert W. Whalin; Gilbert R. Williamson; Jerome L. Mahloch		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station P. O. Box 631, Vicksburg, Miss. 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Office, Chief of Engineers, U. S. Army Washington, D. C. 20314		12. REPORT DATE February 1983
		13. NUMBER OF PAGES 318
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22151.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Civil engineering
Concrete structures
Hydraulic structures
Research

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Development of the U. S. Army Corps of Engineers' Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program is documented in this report. This program will involve research and, where available, the collection and synthesizing of research results on repair, evaluation, maintenance, and rehabilitation of existing Civil Works projects. Primary research problem areas which will be addressed are: Concrete and Steel Structures, Geotechnical, Hydraulics, Coastal, Electrical and Mechanical, Environmental Impact, and Operations Management. (Continued)

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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. ABSTRACT (Continued)

Primary benefits of the REMR Research Program will be to:

a. Permit the Corps to perform its REMR activities in a rapid, quality-oriented, and cost-effective manner.

b. Increase the service life of all Civil Works projects for as long as they are performing their intended purposes and that intended purpose is still being economically accomplished.

c. Correct operational deficiencies in such a way that they will not recurr within the near future.

d. Furnish knowledge to all Federal agencies, state governments, and private concerns involved in related REMR activities.

e. Modify where appropriate existing design and construction procedures so that future REMR problems associated with new facilities will be reduced.

Section A of the report recounts the background of the program and the development of the research problem areas, and summarizes program objectives and funding. Section B is a detailed identification and assessment of the problems in each problem area. Section C presents the details of the recommended research program. Section D discusses technology transfer. A synopsis of the August 1981 REMR Workshop in Arlington, Va., at which many of the REMR problems/needs were identified and assisgned to problem areas, is included as Appendix A.

PREFACE

This report is an outgrowth of recognition that Corps of Engineers workshops previously devoted to design and construction of new hydraulic structures had gradually evolved into workshops related to repair, evaluation, maintenance, and rehabilitation (REMR) of older hydraulic structures. The problems discussed at these workshops revealed that REMR problems could not be completely solved with existing technology for design and construction of new hydraulic structures. Workshops held throughout the country (Pittsburgh, Kansas City, Tampa, Dallas, Seattle, and elsewhere) culminated in a REMR workshop sponsored by the Office Chief of Engineers (OCE), in Arlington, Va., on 4-5 August 1981; this workshop was attended by representatives of the Construction-Operations and Engineering Divisions from every Corps Division office. As a result of the REMR workshop, each Corps office furnished OCE lists of additional problems which should be addressed in the areas of REMR.

In a letter dated 7 April 1982, the Corps' R&D Director assigned the U. S. Army Engineer Waterways Experiment Station (WES) the responsibility for preparing a REMR Research Program Development Report in close coordination with all Corps R&D Laboratories.

This report was prepared during the period 15 April through 1 July 1982 by an interdisciplinary project team from OCE; four WES Laboratories, Structures (SL), Environmental (EL), Geotechnical (GL), and Hydraulics (HL); Construction Engineering Research Laboratory (CERL); Cold Regions Research Engineering Laboratory (CRREL); Coastal Engineering Research Center (CERC); and the Engineer Topographic Laboratory (ETL). Program Manager for preparation of the development report was Mr. John M. Scanlon, Jr., Chief, Concrete Technology Division, SL. Problem Area Leaders were: Mr. James E. McDonald, SL (Concrete and Steel Structures); Mr. Clifford L. McAnear, GL (Geotechnical); Mr. E. Dale Hart, HL (Hydraulics); Dr. Robert W. Whalin, CERC (Coastal); Dr. Gilbert R. Williamson, CERL (Electrical and Mechanical, and Operations Management); and Dr. Jerome L. Mahloch, EL (Environmental Impacts). The principal participants from OCE were Dr. Tony C. Liu, DAEN-CWE-DC, and COL Brian Branagan, CE,

and Mr. James Gottesman, both from DAEN-CWO. Preparation of this development report was under the general direction of Mr. Bryant Mather, Chief, SL.

The research staffs of the Corps' R&D Laboratories contributed significantly to developing the technical program which would respond to the field-identified needs. The field offices contributed valuable information on background problems, photographs, and guidance on appropriate user products. The many individual contributions from the field offices and the R&D Laboratories are gratefully acknowledged and appreciated by the Problem Area Leaders and the Program Manager.

Commander and Director of WES during this period was COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

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Section A

INTRODUCTION, ASSESSMENT SUMMARY AND RECOMMENDED RESEARCH PROGRAM

PART I: INTRODUCTION

Background

The Civil Works program of the U. S. Army Corps of Engineers involves the entire spectrum of water resources development for the Nation and, as such, is unique among all Federal programs. The Corps' role in water resources development traditionally involves planning, design, construction, and operation and maintenance of projects to meet a variety of purposes, including flood damage reduction, navigation, hydropower generation, water supply, recreation resource management, beach erosion control, fish and wildlife enhancement, and environmental enhancement. The distribution of these project purposes by Corps Division is shown in Figure AI-1.

The Corps received its first appropriation for improving navigability of rivers in 1824, and its first flood control authorization (for the Lower Mississippi and Sacramento Rivers) in 1917. Its first hydroelectric power facility was authorized in 1935. During this period, the Corps was primarily concerned with the design and construction of new facilities which would improve the Nation's ability to navigate its rivers, reduce flood damage, produce hydropower, and perform associated responsibilities. One of these associated responsibilities remains an essential task today: to maintain the operational efficiency of the various structures in service at Corps projects. Earlier projects were relatively small and normally before they became too deteriorated were replaced by larger, more modern, and better engineered facilities, many performing multiple purposes.

In August 1965, the Corps issued Engineer Regulation 1110-2-100, "Periodic Inspection and Continuing Evaluation of Completed Civil Works Structures," and as a result in-depth investigations were made of existing structures at Corps facilities. These in-depth investigations revealed an absolute need for repair, evaluation, maintenance, and in some cases rehabilitation of these navigation, hydropower, and flood control structures and channels and harbors. The Corps' need for an increased

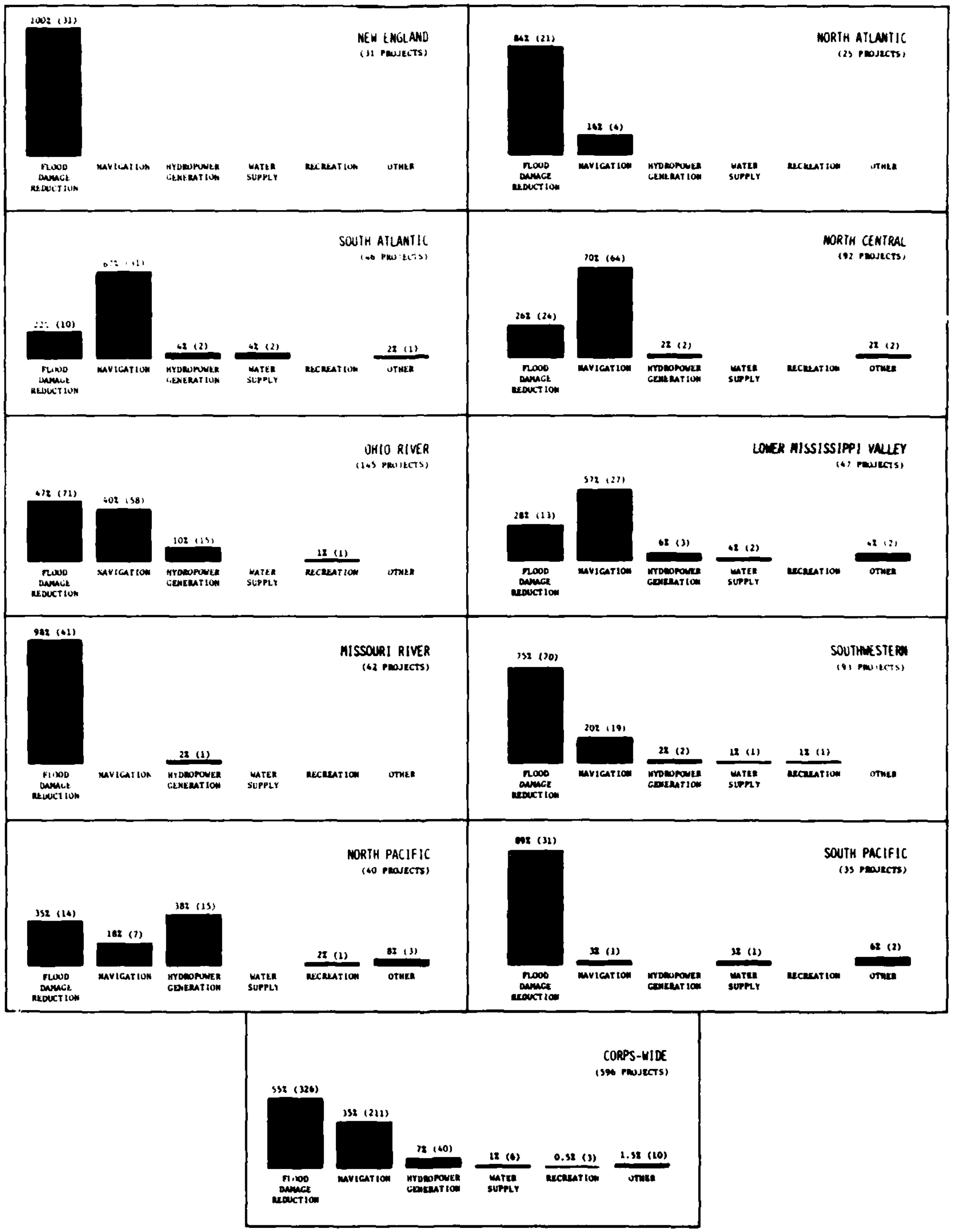


Figure AI-1. Distribution of major Civil Works project purposes by percent and number of projects

Operation and Maintenance (O&M) program was recognized, and the O&M percentage of the total Civil Works appropriation has increased sharply although at a lower rate than inflation. Figure AI-2 depicts the trends in the percentages of the total Civil Works appropriation between 1967 and 1983 relating to General Investigations, O&M, Construction, and other activities.

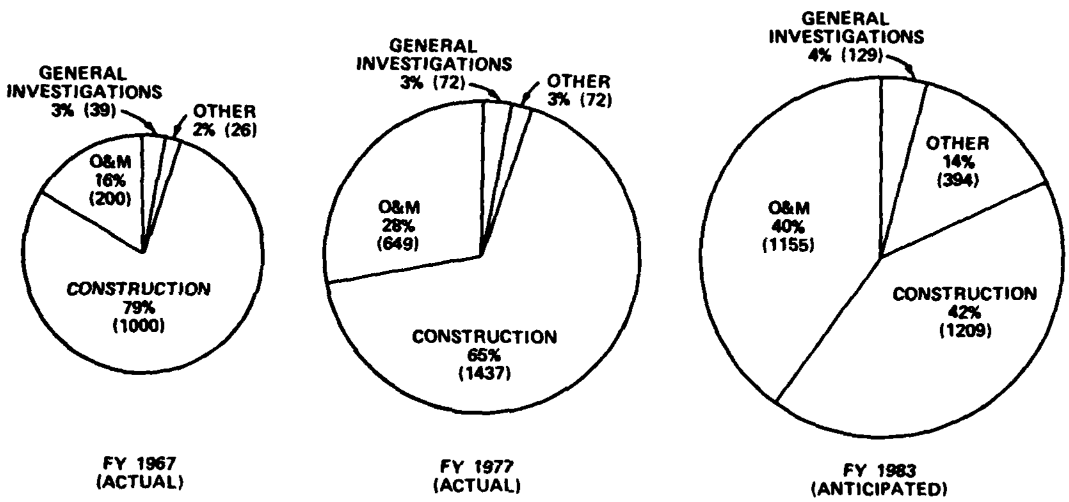


Figure AI-2. Civil Works appropriation trends. Values in parentheses are appropriations in millions of dollars

Authority

The Corps' Waterways Experiment Station (WES) was requested to prepare this development report to address Repair, Evaluation, Maintenance, and Rehabilitation (REMR) problems and their significance and to identify Corps needs associated with these problems, with the stipulation that the report should include, but not be limited to: (a) background and mission objectives, (b) problem identification and assessment, and (c) research requirements and benefits, including a program schedule and associated costs.

Scope of Report

This report attempts to show the increasing role and responsibilities of the Corps of Engineers in repair, evaluation, maintenance, and rehabilitation activities relating to existing Civil Works projects. The report addresses all areas of Corps responsibilities which relate to REMR: concrete and steel structures, geotechnical problems, hydraulic and coastal problems, electrical and mechanical concerns, and associated problem areas such as water quality and environmental effects of REMR and development of an operations management system to provide guidance on scheduling REMR activities.

REMR Terminology

The following definitions are for engineering terms associated with REMR:

a. Repair. To restore damaged or deteriorated elements to serviceable conditions; repair work can normally be performed while a project remains in service.

b. Evaluate. To determine the condition, degree of damage or deterioration, or serviceability and, when appropriate, indicate the need for repair, maintenance, or rehabilitation.

c. Maintain. To take actions that will either prevent or delay damage or deterioration or both; or to correct deficiencies the correction of which will preclude the need for early repair or rehabilitation.

d. Rehabilitate. To make major modifications which if not performed could result in unserviceability; during rehabilitation the project is normally out of service.

Coordination with Other Federal Agencies

Research and investigation studies of many types involving many disciplines are being conducted throughout the agencies and departments of the Federal Government. The Corps of Engineers, Bureau of Reclamation, Tennessee Valley Authority, and Bonneville Power Administration have been meeting biennially to discuss their R&D programs. In addition, during

their November 1981 meeting, representatives from the Soil Conservation Service and Bureau of Mines also attended. One 2-hour session was completely devoted to REMR concerns. Periodic committee meetings are held by representatives of these agencies to prevent duplication and to ensure that research is being performed by the most knowledgeable professionals in particular research areas. (As examples of this coordination, the Corps performs research on nondestructive testing methods with funds furnished by the Bureau of Reclamation, and the Corps provides facilities at Treat Island, Maine, for the Bureau of Reclamation, as well as for other Federal agencies and itself, to expose various concrete specimens to severe weather environments.)

This report was submitted in working draft form to other Federal agencies for formal review, and efforts will continue to ensure liaison and coordination with and, wherever appropriate, participation by these agencies in specific research tasks or work units in the proposed REMR Research Program. As detailed planning continues for the REMR Research Program, contacts with these and other Federal agencies will be expanded to ensure that proposed research tasks build on the latest technical data and do not duplicate research of other agencies.

PART II: CONCLUSIONS AND RECOMMENDATIONS

General

It is estimated that, by FY 1985, O&M funding for existing projects will exceed 50% of the Corps' Civil Works appropriation. O&M and Construction funding have accounted for the following percentages of Civil Works appropriations since 1967:

	O&M	Construction
1967	16%	79%
1970	24%	66%
1977	28%	65%
1980	35%	56%
1983 (estimate)	40%	42%

Unless new construction starts are authorized, this trend will accelerate, and the Corps will be essentially in a REMR posture.

The technology needed for designing and constructing new hydraulic structures is not the same technology needed for repairing, evaluating, maintaining, and rehabilitating existing hydraulic structures and projects. The Corps has always prided itself on its ability to plan, design, construct, and operate hydraulic structures. In the past, when a structure or project reached the point of requiring drastic REMR measures to keep it functioning, it was generally also time to replace it with a larger project. Thus, the Corps has not often dealt with REMR problems on older projects. Existing projects constructed more recently normally have the capacity to function as needed, but with increasing age and use they will require maintenance to continue functioning. The procedures used in either maintaining or rehabilitating them have very little to do with designing and constructing new facilities.

The quantity and age of existing projects have been dramatically increasing. Considering major projects only, there are more than 600 locks, dams, power structures, and multiple-purpose projects with hydropower. As of December 1982, these 600 major projects had the following age distribution:

Age, years	Number	Percentage	Cumulative Percentage
>70	41	6.9	6.9
61-70	15	2.5	9.4
51-60	18	3.0	12.4
41-50	100	16.8	29.2
31-40	67	11.2	40.4
21-30	103	17.3	57.7
11-20	165	27.7	85.4
<10	87	14.6	100.0

Approximately 40% of the 596 major Corps projects were constructed prior to 1952. When the facilities of other Federal agencies, state, and private concerns are also considered, the total known number of dams alone reaches approximately 70,000. Officials responsible for all of these projects will have access to the REMR Research Program results and recommendations.

The importance of Corps Civil Works projects to the Nation's economic growth, transportation, hydropower, water supply, flood damage reduction, and recreation requirements is increasing each year. Evidence of this development can be found in such areas as recreational use of Corps facilities. Such use has increased sharply in recent years among visitors living near projects who choose to vacation near home rather than travel long distances for recreation.

Given the importance of these Civil Works projects, the massive investments of public resources that they represent must be fully considered. Their immense value can best be appreciated in light of recent economic conditions. Inflationary trends in our economy over the past decade have resulted in prohibitively high replacement costs for most of these projects and in strict limitations on new construction, regardless of its merit. The Nation can not afford to allow existing projects to deteriorate or be abandoned so long as their functions are necessary and they are economically competitive with other systems capable of performing the same functions.

Specific

The primary research problem areas which can be logically attacked by the REMR Research Program are:

a. Concrete and Steel Structures.

b. Geotechnical.

c. Hydraulics.

d. Coastal.

e. Electrical and Mechanical.

f. Environmental Impact.

g. Operations Management.

These primary research problem areas will have the following objectives.

Concrete and Steel Structures

The objectives of this problem area are to (a) evaluate the ability of concrete locks and dams and appurtenant concrete and steel structures (outlet works, retaining walls, gates, piles, bulkheads, tunnels, etc.) to perform their intended functions in a given environment; (b) identify material, structural, and functional problems affecting concrete, steel, and associated construction materials; and (c) propose studies to alleviate O&M problems relating to concrete and steel structures.

Geotechnical

The primary concerns in this problem area will relate to remedial measures for seepage problems, liquefaction susceptible foundations in the soils subarea, and development of improved repair and rehabilitation procedures for rock foundations and slope protection. Methodologies will be developed for assessment of structural foundations, for evaluations of remedial seepage control measures, and for predicting the rate and extent of erodibility of rock spillway channels and the identification of preventive measures.

Hydraulics

This problem area will consider the hydraulic performance of inland and estuarine channels and hydraulic structures. In an attempt to find ways of extending the life or operational effectiveness of these

units, research will be undertaken on channel rehabilitation and maintenance for protection against scour, rehabilitating the conveyance elements and operational capabilities of hydraulic structures, and rehabilitation and maintenance operations that will result in improved and safer navigation conditions. This problem area is divided into two subareas: Flood Control and Navigation.

Coastal

In this area, problems associated with repair, evaluation, maintenance and rehabilitation of coastal structures, harbor entrances, coastal channels, and shore protection and restoration will be considered. These include structural damage and the complex wind-wave, tide, and wind-driven circulation effects on the hydrodynamic and sediment processes in coastal environments. Improved techniques for inspection and evaluation will also be considered. Improved methods of reducing maintenance and/or extending the expected life of existing coastal projects will greatly reduce Federal spending in this area.

Electrical and Mechanical

This problem area will be concerned primarily with procedures for maintaining existing gates (such as tainter and miter gates), coatings associated with metallic structures, and corrosion protection for those older structures. Additional concerns will include pumps, generators, valves, coils, and in general all electrical systems, and any other element composed of metallic materials. The primary thrust will be to recommend maintenance procedures and replacement materials when maintenance is no longer feasible.

Environmental Impact

This problem area will be primarily concerned with environmental impacts of the recommended REMR techniques suggested by the other problem areas. Techniques will be evaluated to identify adverse environmental impacts, quantify their magnitudes, and recommend remedial procedures.

Operations Management

The primary concern in this problem area will be to develop and revise existing computer systems or programs to assist in the management

of REMR schedules and needs. The operations management system will input data developed in the other problem areas and provide management with a tool to better control the vast REMR activities in the future.

PART III: RESEARCH PROGRAM

Research Requirements

A considerable number of serious problems were identified in the seven proposed research problem areas during the assessment phase of this study as being amenable to research. A relatively small work unit initiated as a trial balloon in the Civil Works Materials Research Program proved almost immediately how cost-effective a REMR Research Program could be. A small study has just been completed on the spacing of dowels when resurfacing the vertical face of a lock wall; it is estimated that the results of this research alone could save approximately $40 million during the next 10 years. Another modest study proved the inadvisability of using fiber-reinforced concrete in stilling basins to reduce abrasion-erosion. In fact, the study proved that fiber-reinforced concrete erodes faster than similar concrete without the fibers. This research alone reduced the cost of resurfacing a typical stilling basin by more than $150,000.

Given the experience of the Federal Highway Administration in dealing with REMR-type problems on interstate highways and especially bridges, the Corps may well find that the funds necessary to adequately maintain its Civil Works projects are just not available. The only way to be prepared for this eventuality is to conduct research today to develop new solutions to these future problems. Results of the REMR Research Program will enable the Corps, other Federal agencies, state governments, and private concerns to more efficiently and economically repair, evaluate, maintain, and rehabilitate existing Civil Works projects.

This development report includes detailed problem identification and assessments as well as research requirements and benefits for the seven principal problem areas. This information was obtained from potential users of the research through workshops, conferences, and correspondence with the individuals experiencing the problems. An analysis of the problems was undertaken, and they were assigned to appropriate

principal problem areas. Some of the problems related to two or more principal areas and are so addressed in Section B. The problem area leaders and the OCE Technical Monitors incorporated these assigned problems into task areas and work units. The proposed work units were prioritized within each problem area.

The recommended REMR Research Program has been designed and structured to satisfy Corps District and Division R&D needs in solving and reducing high-priority REMR problems and administrative functions. The program will incorporate the results of research conducted by other Federal agencies such as the Bureau of Reclamation, Tennessee Valley Authority, Bonneville Power Administration, Department of Energy, and Environmental Protection Agency and in some instances actually use staff and facilities of these agencies to perform portions of the research.

Table AIII-1 shows the recommended funding levels required to address a program of full response to all the serious problems identified by the staffs of the Divisions, the R&D Laboratories, and OCE. The table is divided into the seven research areas: Concrete and Steel Structures, Geotechnical. Hydraulics, Coastal, Electrical and Mechanical, Environmental Impact, and Operations Management. (In addition, funding levels for Program Management are shown.) The Geotechnical area is further divided into Soils and Rock subareas, and the Hydraulics area into Flood Control and Navigation subareas. These subareas were established for better control by the Technical Monitors in OCE and to forestall problems in drawing on the various Divisions/Districts areas of expertise. Each research area or subarea is divided into major tasks. Detailed descriptions of all work units listed in Table AIII-1 are given in Section C.

Research Benefits

Research directed at repair, evaluation, maintenance, and rehabilitation of existing Civil Works projects will result in numerous tangible returns. These will include: accumulation of detailed knowledge of replacement materials; development of better techniques for evaluating

the condition of facilities; development of rapid and economical procedures to correct deficiencies; and development of computerized programs for anticipating and scheduling REMR activities throughout the Corps.

As a result of this research, the onsite Corps project operator will have guidance on how to correct general maintenance problems and on how to perform minor repair procedures, both of which should contribute to such facilities remaining in service for longer periods of time before major repair or rehabilitation is required. The District maintenance manager will have the information necessary to evaluate the condition of facilities within his area of authority and guidance pertaining to items which need close observation from a safety standpoint. The District engineering staff will be provided with continuously updated information on materials, techniques, and construction practices which should be used to correct major deficiencies.

In general, the primary benefits of the REMR research program will be:

a. Permit the Corps to perform its REMR activities in a rapid, quality-oriented, and cost-effective manner.

b. Increase the service life of all Civil Works projects for as long as they are performing their intended purpose and that intended purpose is still being economically accomplished.

c. Correct operational deficiencies in such a way that they will not recur within the near future.

d. Furnish knowledge to all Federal agencies, state governments, and private concerns involved in related REMR activities.

e. Modify where appropriate existing design and construction procedures so that future REMR problems associated with new facilities are reduced.

Program Management

Program Management is not mentioned directly in either Section B or Section C, but much of the day-to-day technology transfer will be initiated by the Program Manager. It is anticipated that the funding proposed for Program Management will be used, among other things, to accomplish the following:

a. A clearinghouse for REMR-related information will be established. As information is obtained, fact sheets will be written and distributed to potential users for insertion into a previously furnished loose-leaf REMR notebook. This notebook can then be referred by the user until more official documents containing more detailed information are developed, published, and distributed.

b. Video tapes explaining new techniques associated with REMR activities will be produced and distributed for training field personnel.

c. Program Management will also coordinate the activities of the various problem areas and, with assistance of OCE's Research and Development Office, establish priorities between problem areas.

d. Program Management will be responsible for coordinating at least annual research program reviews and semiannual in-process reviews. The Program Manager will also be responsible for the preparation of the yearly work unit documentation.

Table AIII-1

RFMR Research Program Benefits/Funding Summary

Task/Work Unit	Research Benefit	Funding for Cited Fiscal Year, $1000's						
		84	85	86	87	88	89	Total
	Concrete and Steel Structures							
TASK A: EVALUATION OF CONCRETE AND STEEL STRUCTURES								
1. Underwater Survey Techniques	Provide accurate and relatively inexpensive underwater survey systems by which a comprehensive assessment can be made concerning the extent of damage and the need for repair of a structure	50	200	200	[illegible]	[illegible]		750
2. Nondestructive Evaluation of Deteriorated Metal Structures	Provide nondestructive testing techniques and procedures for determining the extent of damage to metal structures caused by corrosion	100	100	50				250
3. Improved Nondestructive Testing Techniques	Provide equipment and procedures which can be used to nondestructively detect the presence, depth, and extent of rebar, cracks, or inferior quality material within concrete structures, locate voids within or beneath structures, and determine in situ structural stability		50	75	75	75	100	[illegible]
4. Structure Damage Index to Determine the Remaining Life and Reliability of Metal Structure	Provide a damage accumulation model for structures, based on their load history and environment, capable of predicting remaining life and probability of reliable operation		50	100	50			[illegible]
5. Methods for Assessing the Condition of Deteriorated Structures	Provide clear and concise guides for accurate determination of the cause and extent of concrete deterioration damage and its effect on the ability of a structure to perform its intended functions				100	100	100	300
	Task	150	400	500	450	400	200	2100
TASK B: MAINTENANCE AND MINOR REMEDIAL MEASURES								
1. Evaluation of Existing Maintenance Materials and Methods	Provide a centralized clearinghouse where field offices can obtain recommendations as to products and techniques for performing specific types of maintenance/repair	50	150	150	150	150	150	800
2. Protective Coatings for Concrete	Evaluate and demonstrate at selected field sites techniques and materials suitable for protection of concrete		150	150	100			400
3. Development of Improved Maintenance Materials and Methods	Develop new or improved maintenance/repair materials with short application time, long service life, suitability over wide ranges of temperature and moisture conditions, and low overall cost		100	150	150	200	200	800
4. Maintenance and Repair of Concrete Shore-Protection Systems	More efficient and economical breakwaters, lower maintenance cost, and safer structures		100	100	100	100	50	450
	Task	50	500	550	500	450	400	2450
TASK C: REPAIR AND REHABILITATION								
1. Repair of Erosion-Damaged Structures	Provide guidance on appropriate materials and repair methods for areas which are susceptible to abrasion-erosion, cavitation-erosion, or both	50	200	150				400
2. Techniques for Underwater Concrete Repairs	Provide guidance concerning rehabilitation conducted underwater to allow field offices to evaluate this option when selecting techniques to be used on a given structure. Develop guidance concerning materials, equipment, procedures, inspection, and evaluation to ensure that satisfactory results are obtained		200	150	100			450
3. Techniques for Removal of Deteriorated Concrete	Evaluate selected concrete removal techniques to determine if they merit recommendation to field offices as alternatives to explosive blasting		150	150	150	50		500
4. Rehabilitation of Navigation Locks	Provide optimum materials and techniques for expedient and durable rehabilitation of concrete lock structures		180	180	100	100	50	610
5. Surface Treatments for Deteriorated Concrete	Provide guidance on selection and application of surface treatments to ensure that they perform as intended in a given environment and do not increase the rate of deterioration beneath the treated areas		100	100	100	100		400

(Continued)

Table AIII-1 (Continued)

Task/Work Unit	Research Benefit	Funding for Cited Fiscal Year, $1000's						
		84	85	86	87	88	89	Total
	Concrete and Steel Structures (Continued)							
TASK C: REPAIR AND REHABILITATION (Continued)								
6. Improved Repair Materials and Techniques	Develop materials and methods which will allow in situ treatment of deteriorated concrete without the necessity for removal of large amounts of concrete		100	100	100	150	200	650
7. Techniques for Joint Repair and Rehabilitation	Provide basic repair/replacement materials and techniques which can be adapted to a variety of joint repair situations		100	150	100	50		400
8. Systems for Improved Structural Stability	Provide new or improved stability criteria for existing structures. Evaluate techniques for increasing structural stability				100	150	350	600
	Task	50	1030	980	750	600	600	4010
TASK D: SURVEILLANCE AND MONITORING								
1. Development and Evaluation of Continuous Monitoring Systems for Structural Safety	Provide systems capable of automatically monitoring the behavior of hydraulic structures		200	200	200			600
2. Improved Field Inspection Techniques and Equipment	Provide new or improved systems that will allow in situ, nondestructive, real-time evaluations of overall structural condition and integrity				100	150	150	400
3. Improved Instrumentation for Older Structures	Provide improved procedures for handling massive amounts of data. Develop new or improved instrumentation for older structures where original instrumentation has failed or is no longer adequate					170	200	370
	Task		200	200	300	320	350	1370
	Area	250	2130	2230	2000	1770	1550	9930
	Geotechnical--Soils Subarea							
TASK A: REMEDIAL IMPROVEMENTS								
1. Rehabilitation Alternatives to Control Levee Underseepage	Reduction in costs associated with excessive rights-of-way, impaired land use, and major restoration	50	150	150	150			500
2. Improvement of Foundation Soils Susceptible to Liquefaction Liquefaction	Savings in hundreds of millions of dollars in prevention of earthquake damage	50	100	100	100			350
3. Remedial Cutoffs and Control Methods for Adverse Seepage in Embankment-Dams and Soil Foundations	Savings in major rehabilitation for seepage control through reliable cost-effective restoration alternatives to observational approach for treating adverse seepage		100	150	200	250	250	950
	Task	100	350	400	450	250	250	1800
TASK B: EVALUATION OF SOIL CONDITIONS AND/OR PERFORMANCE								
1. Allowable Movements and Performance Criteria	Extended useful life and reduction in excessive maintenance or unnecessary rehabilitation by methods for more reliably assessing performance and condition of structures		150	150	100	100	100	600
	Task		150	150	100	100	100	600
TASK C: MAINTENANCE OF SOIL FEATURES								
1. Restoration of Drainage Systems	Less replacement and lower maintenance costs through improved treatment and restoration techniques		150	150	100			400
2. Restoration of Relief Wells	Savings by less frequent replacement through better treatment and restoration methods		100	100	100	100		400
3. Methods for Maintaining Wells and Seepage Control in Cold Regions	Reduced costs for maintaining and/or restoring ice-free conditions by improved operational methods under winter conditions			100	100	100	100	400
4. Geotechnical Applications for Soil Erosion Control and Slope Stabilization	Reduction in economic losses of valuable soils and in costs of protection by improved erosion control methods					100	100	200
5. Erosion Control in Cold Regions	Reduction in damages by ice and winter conditions					100	100	200
	Task		250	350	300	400	300	1600
	Subarea	100	750	900	850	750	650	4000

(Continued)

Table AIII-1 (Continued)

Task/Work Unit	Research Benefit	Funding for Cited Fiscal Year, $1,000's 84	85	86	87	88	89	Total
	Geotechnical--Rock Subarea							
TASK A. REPAIR OF ROCK FEATURES								
1. Grouting Practices for Repair and Rehabilitation of Rock Foundations	Economic enhancement of the safety and life expectancy of Corps structures	100	150	150				400
2. Determination of In Situ Grout Distribution in Structural Foundations	Reduce expensive core drilling operations for verification of grout distribution		125	125	150			400
3. Repair Practices and Quality Control for Rock Slope Protection	Develop guidance to ensure long-term performance of stone protection and armor through better quality control, placement techniques, and monitoring in the toe area		100	100	100			300
	Task	100	375	375	250			1100
TASK B: EVALUATION OF ROCK FEATURES								
1. Geophysical Techniques for Assessment of Existing Structural Foundations	Provide methods for early detection of foundation distress, therefore reducing the cost for remedial treatment		100	200	200			500
2. Methodologies for Evaluating Remedial Seepage Control Measures	Develop new remedial methods or procedures that effectively control seepage based on the flow characteristics of the foundation		150	150	100			400
3. Rock Erosion in Spillway Channels	Early identification of problem areas to provide for timely application of preventive measures, and help define cause, effect, and susceptibility of erosion for various rock types, so that detection and control measures can be improved		150	150	100			400
4. Location and Long-Term Monitoring of Subsurface Water Movement	Development of improved methods for locating and monitoring subsurface water movements to provide early warning of progressively developing hazardous conditions and help define flow paths and boundaries for use in analysis				100	100	100	300
5. Short-Term Weathering and Degradation of Rock Foundations and Slopes	Improved evaluation of stability and pinpointing of critical zones for maintenance or repair				100	150	150	400
6. Selection and Inspection of Rock Reinforcement	Proper selection of rock reinforcement to reduce maintenance costs and increase safety at Corps projects					200	200	400
7. Evaluation of Current Sliding Stability and Deformation Criteria with Respect to the Performance of Aging Foundations	Elimination of blanket application of current stability criteria to old but obviously stable structures that would result in unnecessary and costly remedial measures without benefit					250	250	500
	Task		400	500	600	700	700	2900
	Subarea	100	775	875	850	700	700	4000
	Area	200	1525	1775	1700	1450	1350	8000
	Hydraulics--Flood Control Subarea							
1. High-Level Emergency Spillway Scour	Repair and rehabilitation cost savings ranging from about $1-20 million per project	110	160	150				420
2. Scour Downstream from Stilling Basins	Increased safety at numerous hydraulic structures and savings of $2-3 million at each project if initial repair is inadequate and has to be reworked. Approximately 50 structures on Ohio, Allegheny, Monongahela, and Mississippi Rivers will require scour repair in the next few years; thus, monetary benefits could exceed $100 million		140	150	150	60		500
3. Predictive Techniques for Approach Flow Conditions to Spillways and Others Structures	Development of a numerical code for addressing approach flow conditions to spillways that would complement physical models could result in more cost-effective design and operation of Civil Works and annual engineering design cost savings of $500,00 to $1,000,000		50	100	150	150	50	500
4. Floating Debris Control Systems	Reduced damages to existing structures and adjacent properties, enhancement of purposes and fewer delays, and annual cost savings of about $1,000,000		150	150	150			450
	Subarea	110	500	550	450	210	50	1870

(Continued)

Table AIII-1 (Continued)

Task/Work Unit	Research Benefit	84	85	86	87	88	89	Total
		Funding for Cited Fiscal Year, $1000's						
	Hydraulics--Navigation Subarea							
1. Evaluation of Channel Reaches with High Accident Rates	Evaluation of physical forces and navigator perception, evaluation and response to situations that could exist in the channel, thus allowing identification of channel conditions that might be hazardous. Prevention of similar problems in the future through better design criteria		150	150	150	100		550
2. Lock Gate Impact Barriers	Increased safety at numerous navigation locks, savings of cost to repair damaged miter gates, and reduction in the period of loss of the navigation system to shipping interests while repairs are being made		100	200	200	200	100	800
3. Scour Detection and Repair Around Navigation Training Structures	Reduce number of failures and reduce cost of repairs		150	150	150	150		600
4. Techniques for Repair of Training Structures	More incisive information on repair techniques and effective use of limited maintenance funds		100	100	200	200	100	700
	Subarea		500	600	700	650	200	2650
	Area	110	1000	1150	1150	860	250	4520
	Coastal							
TASK A: COASTAL STRUCTURES								
1. Rehabilitation of Rubble-Mound Structure Toes	Guidance on reliable and successful methods for rehabilitating the toe areas of rubble-mound structures to minimize future expenditures for such repairs	50	200	300	300	250		1100
2. Techniques of Reducing Wave Runup and Overtopping on Coastal Structures	Determine if runup and overtopping are major problems and, if so, quantify dollar magnitude		100	100				200
3. Repair of Localized Damage to Rubble-Mound Structures	Effective and long-lasting means and materials for repair of small but critical areas of breakwater damage		100	100				200
4. Use of Dissimilar Armor for Repair and Rehabilitation of Rubble-Mound Coastal Structures	Information and guidance on reliable methods for repairing and rehabilitating this type of structure		150	150	100	150		550
5. Evaluation of Damage to Underwater Portions of Coastal Structures	Systematic damage evaluation of underwater portions of coastal structures to enable repair to be undertaken before catastrophic events produce extensive damage or destroy the structure		150	150	200	200	50	750
6. Experimental Testing of Methods for Reducing Wave Runup and Overtopping on Coastal Structures	Determine the relative merits of different alternatives for reducing runup and overtopping on coastal structures to provide functional methods for repair and/or rehabilitation				100	150	100	350
7. Experimental Testing of Methods and Materials for Repair of Localized Damage to Rubble-Mound Structures	Definitive information that will allow field engineers to select proper type and size of armor to be used in repairing localized damage and best methods for placing new armor material to ensure stability of structure				100	150	100	350
	Task	50	700	800	800	900	250	3500
TASK B: HARBOR ENTRANCES AND COASTAL CHANNELS								
1. Development of Methods and Techniques for Minimizing Maintenance Requirements of Coastal Navigation Channels	Minimize future maintenance requirements for coastal navigation channels; better quantitative assessment of potential maintenance impacts on coastal regions; definitive prediction of the long-term fate of maintenance material	50	200	200	200	200	50	900
	Task	50	200	200	200	200	50	900
TASK C: SHORE PROTECTION AND RESTORATION								
1. Improved Techniques for Post-Storm Inspection and Evaluation	Improved ability to quantify storm erosion effects by identification and evalution of remote sensing techniques and instruments developed to rapidly and accurately measure bathymetry under adverse weather conditions		100	100	100			300
	Task		100	100	100			300
	Area	100	1000	1100	1100	1100	300	4700

(Continued)

Table AIII-1 (Continued)

Task/Work Unit	Research Benefit	Funding for [illegible] Fiscal Year, $1000's						
		84	85	86	87	88	89	Total
	Electrical and Mechanical							
TASK A: CORROSION MITIGATION DESIGN								
1. Corrosion-Resistant Materials for Civil Works Structures	Evaluate new corrosion-resistant materials and develop a material selection guide for corrosion control in Civil Works structures		100	100	50			250
2. Civil Works Corrosion Mitigation and Management System	Provide techniques to assess and predict the corrosion status of aging Civil Works structures			100	150	100	50	400
	Task		100	200	200	100	50	650
TASK B: PROTECTIVE COATINGS								
1. Painting of Submerged Surfaces	Provide coatings and application methods for the application of protective coatings to steel structures which cannot be de-watered			100	50			150
2. Development of High-Solids Coatings	Provide a durable coating system for use on hydraulic structures exposed to immersion in low-velocity, nonabrasive waters				100	50		150
	Task			100	150	50		300
TASK C: TURBINE, GENERATOR, AND PUMPING STATION REPAIRS								
1. Nondestructive Evaluation of Electrical Insulation in Rotating Machinery	Provide techniques and procedures for determining the existing condition of insulation in generator and motor windings, and for determining the remaining service life		100	100				200
2. Minimization of Cavitation Repair of Turbines	Reduce the amount of cavitation damage that occurs on hydraulic turbines				100	80	40	220
	Task		100	100	100	80	40	420
TASK D: MISCELLANEOUS MAINTENANCE AND REPAIR OF HYDRAULIC STRUCTURES AND EQUIPMENT								
1. Evaluation of Gate Seals and Gate Seal Heaters	Provide guidance to minimize frequency of replacement		40	90				130
2. Evaluation of the Use of SF_6 Circuit Breakers	Evaluate the use of SF_6 circuit breakers at a pump storage hydropower plant		50	50				100
3. Effectiveness of Cathodic Protection Systems	Determine the effectiveness of in-place cathodic protection systems as presently maintained and operated							
4. Use of Synthetic Oils for Exposed Reduction Gears	Determine the effectiveness of synthetic oils for maintaining the operational capacity of exposed machinery reduction gears in cold climates				100			100
5. Energy Management and Control Systems for Corrosion Inhibiting Equipment	Provide procedures and controls to reduce energy consumption for corrosion inhibiting equipment			50	50			100
6. Development of Procedures for Using Vibration as a Maintenance Tool	Provide procedures whereby changes in vibration patterns can be used to predict equipment failures or maintenance needs				100	100	40	240
7. Identification of Basis for O&M Expenditures for Hydraulic Structures	Provide uniform guidelines for prioritizing, reporting, and evaluating O&M expenditures					50	100	150
8. Control of Roosting Birds and Bird Waste	Provide guidelines for detering birds from roosting on Civil Works structures		60	60	30			150
9. Compatibility of Insulating and Lubricating Oils	Provide guidance on the compatibility of different types of insulating oils and of different grades of lubricating o s		60	40				100
10. Fire Protection at Civil Works Structures	Provide a procedure for evaluating the potential fire hazards at Civil Works structures and design criteria for protection systems to alleviate the hazards		60					60
	Task		270	290	280	150	140	1130
	Area		470	690	730	380	230	2500

(Continued)

Table AIII-1 (Concluded)

Task/Work Unit	Research Benefit	Funding for Cited Fiscal Year, $1000's 84	85	86	87	88	89	Total
	Environmental Impacts							
1. Evaluation of Environmental Impacts for REMR	Development of evaluation procedures for screening REMR activities for potential adverse environmental impacts		200	200	200	200	100	900
2. Techniques to Reduce Environmental Impacts for REMR	Development of guidelines to reduce adverse environmental impacts			200	200	200		600
	Area		200	400	400	400	100	1500
	Operations Management							
1. Development of Uniform Evaluation Procedures/Conditions Index for Deteriorated Structures and Equipment	Provide procedures that will allow consistent and uniform evaluation of the present condition of structures and equipment throughout the Corps, with a resulting condition index that will aid in prioritizing the work		300	200	200			700
2. Preparation of Maintenance and Repair Guidelines with Consequence Models	Provide guidelines for determining the most viable maintenance and repair alternatives	50	100	100				250
3. Development of Automated Procedures for Economic Analysis and Life Cycle Costing	Develop automated procedures for performing life cycle cost analysis on maintenance and repair alternatives		100	100				200
4. Development of Computerized Data Management Procedures	Provide an automated system for storing and retrieving information		100	50				150
5. Implementation of the REMR Management System	Provide guidance to OCE and the Districts in the implementation of the REMR Management System	50	100	100	200	250	200	900
	Area	100	700	550	400	250	200	2200
	Program Management							
		150	300	300	300	300	300	1650
	PROGRAM TOTAL	910	7325	8195	7780	6510	4280	35,000

SECTION B

PROBLEM IDENTIFICATION AND ASSESSMENT

PART I: INTRODUCTION

Scope of REMR Problems

The Corps of Engineers currently operates and maintains 536 dams and 260 lock chambers located at 596 sites throughout the United States to meet a variety of purposes. During the initial stages of water resources development in the United States, projects generally had only one of two purposes (i.e., flood control or navigation); thus, projects with these two primary purposes account for approximately 90 percent of the total. There are approximately 220 Civil Works projects having navigation as a primary purpose. While the majority of the Corps' projects are classified as channel and harbor projects, there are over 600 projects within the classifications locks and dams, reservoirs, and multiple-purpose with power.

Investigation into repair, evaluation, maintenance, and rehabilitation (REMR) problems associated with the operation and maintenance (O&M) of these Civil Works projects officially began in 1965 with implementation of Engineer Regulation 1110-2-100, "Periodic Inspection and Continuing Evaluation of Completed Civil Works Structures." Implementation of this regulation caused, for the first time, establishment of interdisciplinary teams of individuals having particular expertise to periodically inspect the condition of existing hydraulic structures. As this program grew and the teams became more knowledgeable in correct inspection procedures, it became apparent that, although all of the structures were receiving good onsite appearance maintenance (keeping grass mowed and other beautification measures), very little had been done in the areas of repair, evaluation, corrective maintenance, and rehabilitation.

Many structures are now expected to be capable of functioning far beyond their original design life, and there is no reason why they should not if the Corps and other responsible agencies have the capabilities and expertise to keep them in safe operating condition to continue performance in an efficient and economical manner. If the purpose for

which a structure was originally constructed can be and has a continuing need to be economically and efficiently performed, the structure should be maintained in a condition which complies with existing design criteria.

Experience has shown that repair and rehabilitation of older facilities requires a variety of kinds of expertise, some of which are different from those required in connection with design and construction of new structures. In problems relating to REMR, the design or construction procedures used may have contributed to the problems; thus, restoring a structure to meet its design criteria using the original construction techniques may result in a requirement to restore it again in a very short time.

Acknowledgement of these problems resulted in several Corps workshops throughout the United States. The first major workshop completely devoted to problems associated with REMR was the Corps' General Concrete Conference held in Pittsburgh, Pa., on 14-18 May 1979. Additional regional conferences have been held at Tampa, Fla.; Arlington, Tex.; Omaha, Nebr.; Olympia, Wash.; Nashville, Tenn.; and St. Paul, Minn. Because of the range of problems/needs expressed during these workshops and problems being addressed by the Corps' R&D Laboratories, a REMR workshop was called by the Office, Chief of Engineers (OCE), to formalize these problems. This workshop was attended by the Division Chiefs of the Construction-Operations and Engineering Divisions or their representatives from each Corps Division office, representatives of six of the eight Corps research laboratories, and members of the OCE technical staff. A synopsis of this workshop is included as Appendix A. This synopsis includes 266 REMR-associated problems/needs which were identified by the participants.

Establishment of Problem Areas

The first order of business after the Waterways Experiment Station (WES) was assigned responsibility for preparing this REMR development report was a meeting at WES of representatives from each Corps Laboratory (Structures, Geotechnical, Hydraulics, Environmental, Construction

Engineering, Cold Regions, Engineer Topographic, and Coastal Engineering) to discuss their input, establish major problem areas, assign problem area leaders, prepare a program outline, and identify milestones and goals to be accomplished on a particular schedule. The major problem areas were established as: Concrete and Steel Structures, Geotechnical, Hydraulics, Coastal, Electrical and Mechanical, Environmental Impact, and Operations Management.

PART II: CONCRETE AND STEEL STRUCTURES

Most of the REMR problems submitted by the potential users pertained to concrete and steel structures. This part of Section B is therefore significantly larger than the others in order to address these many problems. Concrete and steel structures are damaged by a number of causes: impact, environment, internal/external chemical activity, acid waters, deicing agents, floods, and general deterioration with age. Such damage is also quite obvious to those members of the public who visit flood control and hydropower dams, navigation locks, floodwalls, and other Corps of Engineers structures constructed of concrete and steel. In addition, although concrete has been widely used in structures for many years, only recently have dramatic technological advances made possible new applications of concrete in structural engineering.

The Corps of Engineers now operates and maintains 536 dams and 260 lock chambers at 596 sites. More than half of these hydraulic structures are over 20 years of age, more than 40 percent are more than 30 years old, and 29 percent were constructed prior to 1940. Nearly half of the 260 lock chambers along inland waterways will reach their 50-year design lives by the turn of the century. During this same period, annual waterborne traffic is expected to increase some 50 percent according to the National Waterways Study. With the relatively limited number of new construction starts anticipated, many of these structures are being and will continue to be kept in operation well beyond their original design life. It is obvious from visits to these projects and review of periodic inspection reports, that many of the older structures require significant maintenance, repair, and rehabilitation (Figure BII-1). And of course even the relatively new structures must be maintained and preserved to ensure their efficient operation in the future.

There are a wide variety of structures (dams, locks, bridges, floodwalls, breakwaters, etc.) and appurtenances (outlet works, pump stations, tunnels, gates, bulkheads, etc.) associated with the Corps' Civil Works projects. These structures are constructed of materials of varying

a. Tainter gate pier

b. Lock wall

Figure BII-1. Typical concrete deterioration

composition, age, and current condition, and proper maintenance and repair are of utmost importance to their continued efficient operation.

Evaluation of Concrete and Steel Structures

Engineer Regulation 1110-2-100 (OCE 1977) requires that Civil Works structures whose failure or partial failure would endanger the lives of the public or cause substantial property damage be continuously evaluated to ensure their structural safety and stability and their operational adequacy. During the periodic inspections associated with this continuing evaluation, evidence of deterioration or distress is often observed which requires a critical examination for remedial action. Evaluation of older structures is also required to estimate the length of their future service life for replacement/rehabilitation planning purposes.

Basically, the success of any maintenance and repair measures depends upon two factors: first, the accuracy with which the cause and extent of the deterioration/damage has been evaluated; and second, the quality of the judgment that has been used in selecting an appropriate maintenance or repair method. Once a specific conclusion as to the cause and extent of damage has been reached, then and only then can a rational selection be made among alternative maintenance and repair strategies. The necessity for accurate and efficient inspection and evaluation methods and equipment is obvious.

There are a number of mechanisms that can produce premature deterioration of concrete. These include (a) freezing and thawing, (b) aggressive chemical exposure, (c) erosion, (d) corrosion of steel and other embedded material, (e) volume change due to wetting and drying, and (f) chemical reactions of aggregates. The fact that these mechanisms often occur in various combinations within a given concrete structure makes the evaluation process even more difficult.

Corrosion of metal structures and appurtenances (floodwalls, sheetpiles, gates, tunnel linings, etc.) results in billions of dollars of maintenance and repair each year in the United States. Although much

has been done in corrosion mitigation, very little has been accomplished toward developing methods for nondestructive evaluation and service life prediction of metal structures and equipment.

Condition Surveys

A visual examination of exposed concrete is generally the first step in an inspection or condition survey of a concrete structure. The purpose of such an examination is to identify and define areas of deterioration or distress. It is important that the conditions observed be described in unambiguous terms that can later be understood and evaluated by others who have not seen the concrete. To insure uniform descriptions throughout the Corps' field offices, a guide providing standard definitions of terms associated with concrete durability and giving examples of the visual manifestations of the various types of deterioration should be developed.

There are a number of tools available for detecting the extent of deteriorated concrete in addition to visual inspection. The surface boundaries of damaged concrete can be detected by the use of a hammer to indicate drummy areas, by nondestructive techniques like the soniscope, and coring, to name the most common methods. The best evaluation of the quality of concrete is by laboratory examination and testing of randomly selected cores representing the entire structure. However, drilling and core testing are often difficult, always expensive, and usually limited to a small portion of the overall structure. A comprehensive classification system for concrete deterioration incorporating pertinent material properties and observed condition of the concrete would allow correlation of concrete quality and durability between structures. Using such a system, estimates of the concrete quality and the extent of deterioration could be made with a reduced amount of coring and testing required for verification.

Cracks develop in concrete and masonry structures due to many causes including drying shrinkage, carbonation shrinkage, thermal expansion and contraction, foundation movement, structural overloading, and internal expansion due to frost action, sulfate attack, or alkali-aggregate reaction. Such cracking may or may not be of such a nature to

merit maintenance and repair. The cause of the cracking and the degree to which a structure's integrity is threatened must be determined before a decision can be made as to whether remedial action is required. Unfortunately, this is not always the case. Generally, little attempt is made to determine the significance of cracking in concrete, and cracks are routinely treated with various materials to conceal the cracking. In most cases results are less than desired (Figure BII-2), and in many cases remedial action was not required in the first place. Oliver Lock and Dam was constructed in the late 1930's. By the late 40's cracking had developed to such a degree that a board of inquiry was formed and an investigation was conducted to establish the cause and recommend remedial measures. Alkali-silica reaction was determined to be the cause and the recommendation relating to remedies was: "don't do anything now." Although one's initial reaction to the appearance of the concrete in the lock (Figure BII-3) probably would be that some sort of remedial action was required, a reassessment of the concrete's condition in 1976 again found that extensive maintenance and repair was not necessary.

Available equipment and methods for accurately locating and tracing cracks within concrete structures should be examined and refined. Also, techniques for determining the consequences of cracking in Civil Works structures should be developed. This, in combination with procedures to determine causes of cracking, would be used to develop guides to determine the significance of the various types of cracking.

Some cracking of concrete in structures can be attributed to excessive stress, design errors, or construction errors, or a combination of the three. Critical residual stresses may develop and cause concrete cracking which could then compromise the integrity of the structure. The problem is to locate possible areas of high stress concentrations and determine the stress fields. Structures where instrumentation systems were not incorporated into their project design can not be readily monitored for internal disturbances such as stress buildup. Present overcoring techniques can indicate residual stress fields; however, equipment design and operational procedures account for limited or expensive use of the techniques. Generally, tunnels and galleries within

Figure BII-2. Cracking which has propagated through improper repair material

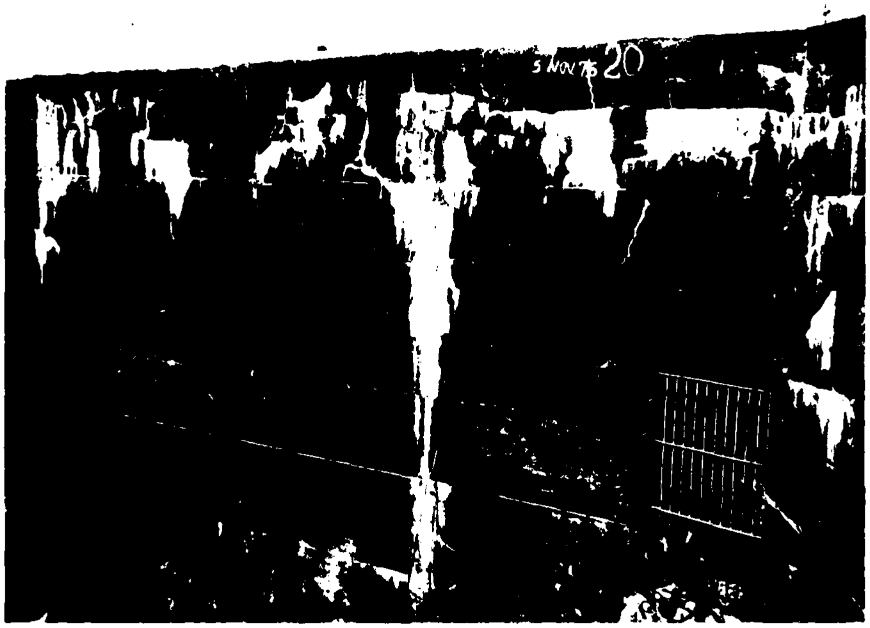


Figure BII-3. Concrete cracking due to alkali-silica reaction

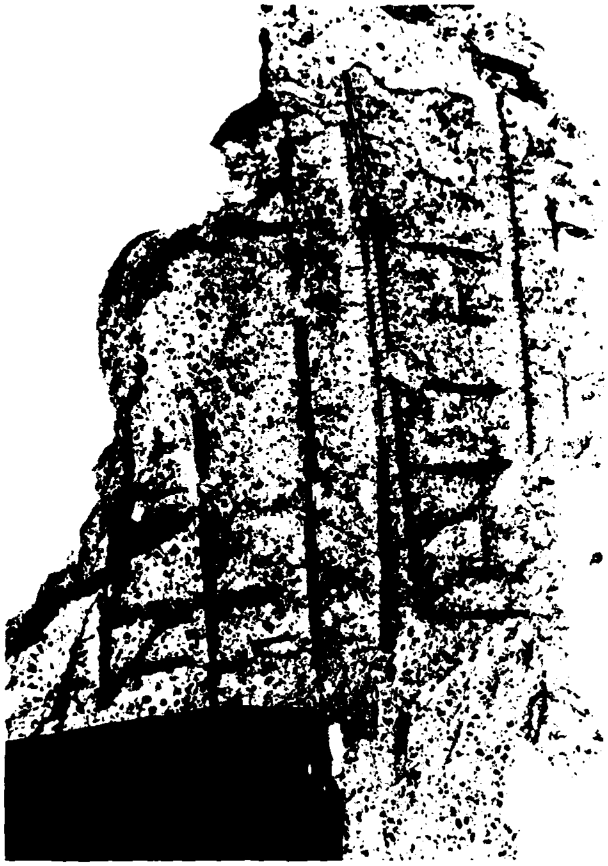


Figure BII-4. Concrete spalling due to
corrosion of the reinforcement

concrete dams are small and do not provide room for overcoring equipment. Research is needed which will make available overcoring equipment that is flexible and hence easier to operate in small spaces. The state of the art in drilling to include articulated drill stem or drive mechanism needs to be advanced. Drilling equipment capable of drilling at angles up to 90 degrees will allow access in hard-to-get-at spaces.

The corrosion of metallic items embedded in concrete structures causes much damage annually (Figure BII-4). It may manifest itself as spalled concrete, cracks in the concrete, staining of concrete surfaces, or structural movement, but in any case it causes damage that is costly

to repair and replace. The adverse effects of corrosion are related to the type of metal and to its structural role in the structure. If we are talking about reinforcing steel, spalling produces unsightly chips in the concrete that expose the steel and promote and encourage further corrosion with increasing loss both of steel and concrete cross sectional load carrying capacity. Embedded items that are nonstructural may be protective, such as prestressing strand conduit. Loss of this protective covering can allow corrosion to the prestressing strands it was meant to protect. These problems have been recognized for some time and several attempts to combat the situation have been made. Most notably, the use of half-cell potential measurement has been the most effective method of detecting this problem. It can tell where there is active corrosion to embedded metals, but it cannot tell whether the condition is severe. Chaining is another successfully used method, but it does not tell the full extent of the damage or the entire area covered by it. New techniques and equipment are needed that could be used to detect corrosion when it is in its infant stage and indicate that remedial action is needed before more elaborate damage occurs.

The evaluation of the walls or outer surfaces of masonry structures presents a unique problem in that existing classical methods (soniscope, Schmidt hammer, coring) do not lend themselves to data collection for this type structure. Therefore, past attempts to make this evaluation have been to address a very narrow band of causes of obvious defects or problems such as rain infiltration and frost damage. A technique is needed that will evaluate not only the wall itself but also the individual components of the wall (brick, mortar, blocks, and adjacent interior wall covering material), and the function and required properties of each. This technique should be designed as a system, composed of tests (lab and field), that will address these areas of required data.

Engineering data are being obtained in various degrees of completeness on existing structures in order to determine if and when rehabilitation work should be performed. In most cases, decisions are made concerning rehabilitation efforts without an overall economic evaluation

of the structure in relation to its expected service life. One of the main reasons for this is that there are no guidelines for establishing the service life of structures. Now when the service life of a structure is given, it is usually a personal judgment. Without guidelines, which make the judgment of service life of a structure more objective and based on in-depth evaluations, the decisions about structure rehabilitation can be in error. The service life of a structure is an essential parameter in a total economic evaluation of a structure and evaluation techniques should be developed and sequenced into a total economic evaluation system for structures.

Structural Evaluation

Presumably, the as-built resistance of existing Corps' structures was adequate by a comfortable margin for the loadings anticipated during its design. However, since loadings sometimes increase under current operational practices and/or resistances sometimes decrease due to deterioration, there often is a need to evaluate the reliability of existing Corps' structures. If this evaluation is not done, the costs of either unnecessarily performed or unperformed necessary rehabilitation can clearly be substantial. While core drilling and testing provides selective data on condition and material properties, the restrictive nature and economics of this technique negate comprehensive technical evaluations. Also, when only rubble is recovered during a coring operation (Figure BII-5), obviously no cores are available for testing and material properties such as strength and elasticity have to be estimated. This emphasizes the need for nondestructive tests for in situ structural evaluation. Nondestructive techniques are needed to detect the presence, depth, and extent of rebar, cracks, or inferior quality material within concrete structures, and locate voids within, behind, or underneath concrete structures. Measurements have been made in the laboratory on thin sections (1-ft or less) of concrete using the "pulse-echo" method of ultrasonic testing with limited success; i.e., results have been of acceptable accuracy, but improvement is needed in resolution and measurement efficiency.

Figure BII-5. Example of concrete core from a deteriorated structure

Situations continue to arise which require that we "look into" or define boundaries within concrete structures which have only one surface accessible. In May 1977, an inquiry was received by WES from the Savannah District concerning the availability of a method or technique for determining the depth of driven concrete piles which served as foundation and support piers for a concrete loading wharf in Kings Bay, Ga. (Figure BII-6a). After limited field testing a short-term investigation was performed in early June 1977. The performance of the system and the overall results of the investigation were considered to be acceptable, but difficulty with signal analysis because of extraneous reflections left some questions unanswered and pointed out inadequacies of the system in its stage of development at that time.

In 1979 the New Orleans District became concerned about the continuity of some of the prestressed concrete piles that were driven to serve as foundation for an inverted T-wall structure in the Atchafalaya

a. Loading wharf

b. Inverted T-wall structure

Figure B11-6. Examples of situations where it is desirable to evaluate concrete condition with only one accessible surface

Basin (Figure BII-6b). Attempts to make pulse-echo measurements in the support piles by exciting them through the 2.5-ft base slab were unsuccessful. Attempts to perform shear mode pulse-echo measurements after some excavation were also unsuccessful.

At this point in development, successful pulse-echo measurements can be made on driven piles and drilled piers in low-damping environments (water, sandy soil, etc.) and where extraneous reflections carried by adjoining elements are minimal. Improvements have been made in the equipment, the understanding of the phenomena that occur, and in data collection and processing, but more research and development is needed in order to provide a pulse-echo system capable of making accurate, reliable measurements on long, thin members in high-damping and complex geometrical environments.

Many times assistance is requested in situations which involve assessment of cracking or deterioration of massive concrete structures where only one side of the structure is accessible. In these cases, pulse-echo measurements would be applicable. Due to manpower and budgetary restraints, and the fact that there are more requests concerning thin sections and long thin members, there has been little effort in development of a pulse-echo system to investigate massive concrete structures. This technique is needed and would greatly enhance overall evaluative capabilities.

Conventional rigid body analysis is the method used to evaluate the stability of existing structures. In most all cases, the older lock and dam monoliths do not meet present-day criteria when evaluated by conventional rigid body analysis. Since the conventional rigid body analysis is based on various assumptions and simplifications, the locks and dams may, in fact, be safer in-place than the stability computations indicate. This is true because the computations are slanted toward conservatism and inherent stabilizing factors. An example of an inherent stabilizing factor is the monolith base that is considered flat in analysis, when in fact, it may be irregular and keyed into the foundation producing a greater sliding safety factor.

Previously, the structures which did not meet present-day criteria have been modified (posttensioning, reaction block, etc.) at considerable expense. For example, stability rehabilitation alone at Brandon Road Dam cost in excess of $3 million. Another and more serious situation is that inherent safety factors do not have to always exist; therefore, a structure which is marginal in stability could fail.

It would be highly desirable to excite a structure in the field and determine its in-place stability. Such in situ testing would reveal unsafe conditions and they could be corrected before major problems occur. Also, there is the potential for savings of millions of dollars in reducing or eliminating remedial measures for structures which are determined by in situ performance capability to be actually safe in field tests.

As this problem is shared by the structural engineering profession in general (Shinoyuka and Yao 1981), this work unit should maintain cognizance of other research while concentrating on the pecularities of the Corps problems. With the advent of portable computers, the dynamic testing of Corps structures in service (Sweet, Genin, and Mlakar 1977; Galambos and Mayes 1978; Baldwin, Salane, and Duffield 1978) appears to be a practical and reliable technique to estimate their structural integrity. The feasibility of using such a technique for Corps structures should be investigated.

The seismic safety of most Corps' Civil Works structures was assured in their design through a seismic coefficient analysis. Since this procedure is now generally accepted to bear only a remote resemblance to actual seismic response, the Corps bears a responsibility to reassure the public that these vitally important structures will function as intended following a regionally devastating earthquake rather than exacerbating the disaster through their failure. Research recently conducted under the Structural Engineering Program has improved this situation somewhat but has also identified a number of items requiring further study. The product of this work would be practical and defensible procedures for the seismic re-evaluation of existing structures.

Underwater Surveys

Dewatering of many projects or appurtenant structures to perform inspections and repairs is difficult and very expensive. In some cases, such as breakwaters, jetties, piers, embankments, etc., dewatering is practically impossible. In any case, the disruption in project operations associated with the dewatering of most structures, particularly hydro-power dams and navigation locks, cannot be tolerated for sufficient lengths of time to conduct detailed surveys and examinations. Obviously, there is a need for improved techniques to examine structural features in detail underwater. Areas of application would include examination of (a) erosion damage and debris accumulation in stilling basins, discharge laterals, outlet channels, etc., (b) cavitation damage to sluices and sluice gates, (c) scour along lock walls to locate undermining, (d) conduits, draft tubes, and tailraces, (e) intake towers and tunnels, (f) channels to locate rock outcropping or other hazards to navigation, (g) erosion of embankments and concrete revetments, and (h) breakwaters, both floating and fixed.

Divers have been used frequently in underwater surveys; however, in many cases the usefulness of such surveys is limited due to the divers' inability to describe in engineering terms what he is observing in addition to problems of orientation and location. Visual inspection could be greatly improved by underwater television cameras and videotape recorders, so that the results can be re-examined as often as desired in better surroundings. Hand-held cameras could be used, but it would be preferable to use unmanned remotely controlled equipment in order to avoid the need for divers to work in hazardous conditions.

The first use of an unmanned underwater vehicle for inspection of tunnels with significant length was at Fort Peck Dam in 1977. The four 24-ft-diameter tunnels upstream from the control gates range in length from 1900 to 2600 ft, and each has a 100-deg horizontal curve. The intakes at the upstream end of the tunnels are accessible only by diver. The tunnels can be unwatered by moving trashracks and installing

bulkheads; however, divers are required during this operation. The tops of the intakes are approximately 150 ft below the water surface during high pool.

The vehicle used was developed for use in the ocean where some natural light is available and there is basically no turbidity in the water (Wiendieck and Freitag 1970). Although the vehicle performed fairly well with the exception of difficulty in pulling its power cable around the horizontal curve to the end of the tunnel, some additional features appear desirable; lights should be able to rotate, the vehicle should have additional lighting of variable intensity which could be turned on and off. Also, the type of camera to be used should be investigated to determine which would give the best picture under various water conditions.

A complete unwatering and visual inspection was estimated to cost between $500,000 and $800,000. The cost of the inspection using an underwater vehicle was approximately $130,000.

In many other areas of potential application for underwater survey, the environment may be more severe (high-velocity flow, turbid water, hazardous areas, etc.) than previously experienced. Some areas will require remotely controlled cleaning equipment to remove marine growth, silt, and other debris from the surface to be examined. Ideally, such equipment would operate without requiring any permanent attachments to the structure being observed. Once the structure has been cleaned, visual inspection may indicate that tests should be conducted at specific locations on the structure, therefore a variety of nondestructive testing techniques capable of use underwater should be developed.

Systems and technology presently available which might be applicable to mapping and profiling of surfaces underwater should be investigated. These include airborne laser systems, acoustic profilers, and downward-looking radar. The feasibility of using high-resolution acoustic holographic imaging to map the surface contours of the lock floor at Lock and Dam No. 26, Mississippi River, has been studied. Improvements to both hardware and software to enhance the accuracy and operational efficiency are required to facilitate its use in typical Corps

applications including mapping and profiling of lock floors, stilling basin slabs, channels, underwater revetments, etc.

Maintenance and Minor Remedial Measures

A great deal of maintenance and repair work has been accomplished within the Corps of Engineers in recent years. These have been accomplished by in-house labor forces from either the Construction-Operations or Engineering Divisions, by hired labor, or by contractors. In spite of the large numbers of projects and the variety of techniques and materials used, there is very little documentation available on the long-term performance of the maintenance and repairs.

Essentially, each District is on its own with little or no feedback, other than the manufacturer or his salesperson, on how a particular product has performed. Since the marketer has a vested interest in making a profit by selling as much of his product as possible, this is not an ideal climate for the user. If in the interest of staying abreast of current technology and minimizing expenditures a new product is used or misused such that the results are undesirable, then all parties suffer, possibly needlessly. As an example, an epoxy marketed as a material for bonding new concrete to old concrete was subjected to limited laboratory testing. Results showed that the bond strength using this material was less than 25 percent of that of the control without any bonding agent. After considerable probing and discussion the marketer finally admitted that the product could not be used in a moist environment. There was no mention of this limitation in the sales brochures. On the other hand, limited laboratory evaluation of a fast-setting concrete for small-scale patching of concrete pavements and bridge decks showed the strength gain was as rapid and as high as sales brochures claimed. This material is now being used as a quick-setting patching material.

The Corps has been extremely reluctant to identify products by name, whether they performed well or not. There is simply not enough funding available to continue field experimentation each time a

maintenance or repair project is initiated. Reasonable acceptance criteria should be developed for different classes of repair materials so that objective evaluations will be the norm and the user will be the beneficiary. Once these evaluations are made, there needs to be a centralized point where Districts can obtain recommendations as to products and techniques for performing specific types of maintenance/repair as well as to report on similar types of work that they have already done. Also, there must be an organized system which insures that follow-up performance data are obtained and made available on a regular basis. The potential savings of such a clearinghouse are significant. The potential legal problems associated with the system are also significant and must not be overlooked.

Expedient Concrete Patching

To alleviate the project downtime due to maintenance and repair, there is an expanding interest in materials for rapid repair/maintenance of concrete surfaces and structures such as navigation locks subject to heavy traffic. Industry has been aware of this potential market for some time and personnel responsible for concrete maintenance have been flooded with offers of "miracle" materials. Many of these materials are adequate for some situations, provided they are used within the limitations of exposure recognized and expressed by the supplier; some may be of little merit. Others may be inappropriate for general use because they are too expensive or they lack durability (Figure BII-7).

Many repairs have been made throughout the country to demonstrate materials claimed to be new and improved products. Much of this work has been done without adequate means of evaluating the product and comparing its performance with that of other patching materials in the same environment. In some cases the product was not new at all but just had a new brand name. Current knowledge on the identity, use, and effectiveness of rapid-setting, cast-in-place materials for patching concrete should be collected and evaluated. Particular consideration should be given to materials, costs, patch preparation time, and exposure conditions. Desirable features of a maintenance/repair material include

Figure BII-7. Concrete patch failure

short application time, long service life, suitability over a wide range of temperatures and moisture conditions, and low overall cost.

Concrete Surface Preparation

Proper surface preparation of concrete is extremely important when performing maintenance or repairing concrete with various materials. Different surface preparation techniques are needed for different materials and the specific types of maintenance and repair. Coatings, overlays, and patches have failed in short periods of time because of improper surface preparation. When these repairs fail, the concrete has to be repaired a second time which is costly and may occur again if the surface preparation technique is not changed. Many different techniques have been attempted in the past, such as installation of anchors, different bonding agents, saw-cuts, sandblasting, chemically cleaning, and combinations of these techniques. Some preparation methods have been successful where others have failed. The evaluation of concrete preparation techniques should be pursued to determine which techniques should be adopted for specific types of maintenance and repair materials.

Maintenance of Joints

In most concrete structures, all concrete-to-concrete joints (contraction, expansion, and construction), and the periphery of openings left for other purposes, require sealing. Some exceptions are contraction joints (and cracks) that have very narrow openings and certain construction joints. The specific function of sealants is to prevent the intrusion of liquids (sometimes under pressure), solids or gases, and to protect the concrete against damage. Sealants must often function while subject to repeated contractions and expansions as the joint opens and closes and while exposed to heat, cold, moisture, sunlight, and sometimes, aggressive chemicals. Therefore, few exposed sealants have a life as long as that of the structure whose joints they are intended to seal. Most field-molded sealants will require renewal sooner or later if an effective seal is to be maintained and deterioration of the structure is to be avoided. The time at which this becomes necessary is determined by service conditions, by the type of material used, and whether any defects were built in at the time of the original sealing.

Much experience of poor sealant performance and resulting damage to a wide variety of structures exists. Failures continue to occur often within days and weeks rather than months or years for the following major reasons:

a. The joint as designed was of an impossible width and shape with respect to potential movement of the structure, but it was constructed that way and sealed.

b. Unanticipated service conditions have resulted in greater joint movements than those allowed for when the joint design and type of sealant were determined.

c. The wrong type of sealant for the particular conditions was selected, often on the false grounds of economy in first cost.

d. New sealants have sometimes been initially overpromoted and used before their limitations were realized.

e. Poor workmanship occurred when constructing the joint, in preparing it to receive the sealant, or during sealant installation.

There are many different types of materials now being used to seal joints, however, few have been totally successful because (a) the

material was not tailored to the joint design and spacing, (b) the sealant was not durable enough for the movement occurring at the joint, and (c) sealant weathering. Poor application techniques have also contributed to the failure rate. Selection of inferior joint sealant materials will lead to increased maintenance of the joints. Because of the large variety of materials available and specifications covering these materials, it is sometimes difficult for the user to select the right type of sealant for a specific type of joint. Maintenance requires that the old sealant be removed and replaced with the same type of sealant or another type. Usually the problem will continue to exist. Most specifications of joint sealants do not require a weathering test, tensile adhesion, or fatigue test. There is a need to evaluate different types of joint sealant materials to determine which ones would be more serviceable.

Concrete Cracking

In spite of the best efforts of engineers, builders, and inspectors, cracking in concrete structures is the maintenance and repair problem most frequently encountered. Although the causes for almost all types of cracking are known and, in theory, most cracking can be prevented through proper structural design, careful aggregate and cement selection and concrete proportioning, and correct concrete placing, finishing, and curing, concrete continues to crack. While cracking should by no means be accepted as inevitable, prevention is by far the best cure, field personnel must be able to deal with those cracks that do occur.

The most important factors that may cause cracking include design errors, temperature stresses, chemical reactions, corrosion of embedded metal, weathering (freezing and thawing), poor design details, and differential foundation movements. The wide variety of factors that may cause cracking should suggest that there is no single repair technique which will work in all instances. A repair technique which is appropriate in one instance may be ineffective or even detrimental in others. For example, if a cracked section requires tensile reinforcement or post-tensioning in order to be able to carry imposed loads, routing and filling the cracks with a waterproofing sealer would be ineffective but harmless. On the other hand, if a concrete section has cracked due to

improper spacing of contraction joints, filling the cracks with a high strength material such as epoxy will only cause new cracking to occur as the concrete goes through its next contraction cycle.

Once the cause of cracking has been established, a maintenance/ repair technique(s) must be selected. Just as there are a wide variety of causes of cracking, there are an equally wide variety of possible repair techniques. The most frequently used techniques for maintenance/ repair of cracks include autogenous healing, blanketing, drilling and plugging, drypacking, epoxy injection, grouting, judicious neglect, overlays, polymer impregnation, posttensioning (external stressing), providing a new joint, routing and sealing, and stitching.

The key to successful solution of the cracking problem is to match the maintenance/repair technique to the cause of the cracking. Therefore, detailed guidance should be developed for field personnel on how to evaluate the causes of cracking and how to select a maintenance/repair technique. Also, step-by-step instructions should be developed for application of the most frequently used techniques.

Backing Materials

In recent years the Corps of Engineers has installed an epoxy resin compound as a backing material for quoin and miter blocks in lieu of a specified zinc filler. The specifications for this material are restrictive in that it designates a certain epoxy resin or approved equal. This material has failed to set up occasionally, and it is now required that the material be tested for hardness prior to placement. There are numerous other materials which could replace the one above if the desired properties were known. Laboratory evaluation is needed in order to determine these properties and evaluate different materials so that better specifications could be written.

Protective Coatings and Patches

Many of the Corps' older concrete structures require action to protect them from chemical attack, weathering, erosion, etc., to prevent eventual destruction of the existing concrete. One approach is to coat the concrete with a material that is more resistant to phenomena which are causing deterioration of the original concrete. The Corps has used

various coatings in the past, and some have been successful where others have failed. In most cases, the failures were due to choosing the wrong coating or improper application. Also, the Corps has used epoxy coatings for protecting concrete from weak aggressive chemicals when a less expensive coating may have been just as successful. There is a need to evaluate various chemical types of coatings to determine which ones are more durable, less expensive, and the proper ways to apply these coatings.

Shotcrete has frequently been used during major rehabilitation work accomplished at locks and dams. However, results to date have been mixed. Poor materials, poor workmanship, and lack of entrained air in the shotcrete are a few of the problems which have resulted in poor quality work. Conversely, excellent quality work has been achieved when proper quality control procedures are followed. Previous shotcrete repair jobs should be reviewed to determine reasons for success or failure. Based on this review, work should be initiated as necessary to establish quality control tests, allowable variations in procedures and materials, and methods to entrain air where air entrainment is required for durability.

Due to the scope and complexity of rehabilitation projects, they are usually accomplished by contract. However, a small hand-held dry process shotcrete gun developed by the Missouri River Division (Coy 1974) appears suitable for application of mortar in smaller repairs using in-house labor. The device is easily assembled from readily available material, has only a few critical dimensions, and can be operated by personnel without extensive training. The repair and maintenance patches produced bond well to the existing concrete, and should have excellent durability. The material can be finished with customary tools and should match existing concrete well enough to provide a pleasing overall appearance. Further evaluation is needed to establish the feasibility of this device as a technique for repair of small areas of damage and routine maintenance activities using in-house labor forces.

Skid-Resistant Overlays

The concrete surfaces on many older Corps structures have become worn from normal traffic. This has resulted in slippery operating

conditions for foot and small vehicular traffic on the tops of lock walls, for example, particularly during periods of inclement weather. Very thin mortar overlays containing selected aggregate for skid resistance and admixtures for good adhesion have been used to establish the skid resistance of concrete pavement. The feasibility of using this approach on Corps structures should be investigated.

Concrete Bank Stabilization

Articulated concrete mattress (ACM) is used extensively for revetments along the lower Mississippi River. Although maintenance costs are less than 2 percent of the original construction, they still amount to millions of dollars annually.

Cross sections of the reveted area are taken annually for comparison to the cross sections taken immediately following construction. As long as the ACM remains at the same or a higher elevation than the original it is considered to be functioning as desired. Failures appear as circular depressions or holes in the ACM and may occur in less than a year or over a period of years. Since the majority of ACM is sunk in 10 to 200 ft of water, the cause(s) of failure are unknown to a large extent. One theory is that failure results from the sand beneath the ACM being sucked through the openings in the mattress under certain hydraulic conditions. Maintenance and repair consists of overlaying the failed area with an additional layer of ACM.

Existing failure areas should be examined in detail to determine the cause(s) of failure. Based on this determination, techniques should be developed to reduce the extent and rate of failure. Techniques which appear to have potential application include filter cloths behind the ACM, improved end ties for anchoring the mattress, reduced openings between individual sections, and larger sizes of sections.

Building Maintenance

In addition to its hydraulic structures, the Corps owns and maintains thousands of buildings ranging in size and complexity from rest rooms to powerhouses. Many of these buildings are constructed of concrete, brick, and masonry and various combinations of these materials.

Roof decks for concrete structures usually are either built-up (layers of roofing felt covered by a natural granular aggregate) or a pumped in-place lightweight grout. In spite of rather frequent maintenance and repair to offset the effects of weathering, these systems often exhibit significant leakage. These leaks damage ceilings, interior walls, and floors in addition to building contents. New materials and deck systems which will reduce the effects of weathering and produce a much better water barrier should be identified and evaluated. There are several new synthetic material systems available (nonclassical for roof decks) which appear to lend themselves to this application.

There is an increasing number of occurrences of functional failure of the exterior walls in brick and masonry structures associated with weathering and age (Figure BII-8). Materials and techniques for the maintenance/repair of brick and masonry structures are very common but many of them are ineffective, especially in specific applications. Techniques range from one-coat applications of water-barrier material to removal and replacement of wall sections. In many cases, the selection of materials and techniques is based on manufacturers' claims about specific products. Also, maintenance and repair is concentrated on immediate remedial actions to the most obviously affected places rather than long-term systems to the complete structure. This method does not prevent further occurrences in the same structure which necessitates additional maintenance/repair on a continuing basis. Objective evaluations of materials and techniques for specific applications are required to identify those systems that can be used to repair localized failures as well as provide protection for the remainder of the structure.

Porous masonry and stone surfaces which are subjected to freeze-thaw environments are often damaged. If the surfaces of these materials are not properly protected, spalling will occur. In order to preserve the surfaces of these materials, the surface is generally coated or chemically sealed using one of the many different types of coatings and sealants manufactured by industry for this purpose. The performance of those coatings and sealants used in the past has varied widely.

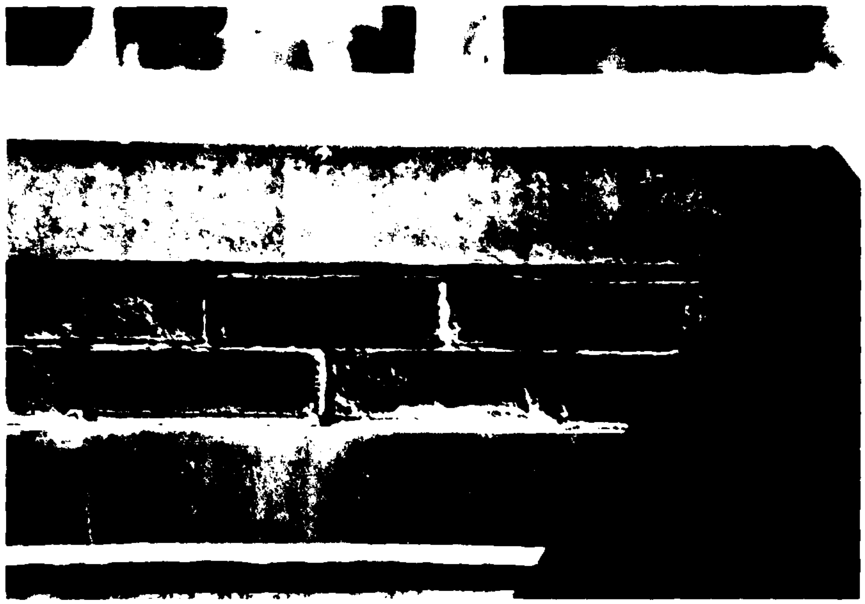


Figure BII-8. Failure of exterior brick wall

Therefore, there is a need to evaluate the different types for adhesion, durability to weathering, permeability, ease of application, vapor-transmission, and cost.

Boating Facilities

The Corps of Engineers provides many recreational facilities along the lakes and rivers that it maintains. These facilities include mooring piers and docks, fishing piers, boat loading facilities, and ramps. Their maintenance is a highly visible indicator of the Corps' attitude toward the public it serves. At many locations, this maintenance is routine, however, in fluctuating lakes and fast moving rivers excessive damage to such facilities can become a major problem. Scour to pilings, damage to moorings due to rapid current, buildup of sediment in calm water areas, and impact damage from debris and water craft can cause rapid deterioration of the facilities. Efficient methods of maintaining and repairing these facilities are needed that will provide lasting structures and enhance the Corps image in these areas.

Many of the Corps older marine structures are founded on timber piling. Piles can deteriorate due to biological processes (worms, rot), chemical deterioration, physical processes (abrasion, impact, overloading). Each of these causes produces a distinct form of pile failure. For instance, rotting and worm damage reduce cross sections, but it is generally from the inside out, while abrasion reduces cross sections from the outside in. These two types of deterioration call for different types of repair. In the instance of the rot a maintenance and repair material that could penetrate into the decayed structure, such as an epoxy resin, would be preferable to encasing the rotting area in, say, concrete. However, building the cross sections with a concrete jacket would be an acceptable solution in a case where the central portion of the remaining cross section was still sound. Splitting by overload might call for additional confining forces that could be provided by a tightening collar whereas a moment type of failure caused by lateral impact might require splicing of the damaged section.

There are many materials that are available to repair timber piling. These include timber, steel, concrete, polymers, fiberglass, wire mesh, reinforcing dowels. These materials should be analyzed and categorized according to the type of failure condition they are best suited for repairing. In this way proper materials could be matched to a particular type of repair situation. Techniques for reaching deteriorated areas of piling should be studied. In many cases, piling is under water, earth, or both and in order to perform in situ repair, techniques such as cofferdamming, injection, jacking, drilling need to be studied and methods of accomplishing the repair recommended. Cost of the particular type of repair and duration of the repair in satisfactory condition should also be addressed to allow a user to make a more intelligent choice of repair. Finally, research into new materials that will solve existing repair needs as well as prevent future deterioration should be addressed.

The Corps has used precast concrete armor units in a variety of shapes and sizes in breakwater construction. Premature breakage of individual armor units has occurred in several instances resulting in

functional deterioration of the structure's overall stability and purpose. Precast concrete floating breakwaters are being increasingly used for expedient protection. Floating structures have been considered for, and in most cases constructed, as marine and port breakwaters, roadways, loading docks, temporary ports and bridges, recreation piers, shore erosion protection structures, and oil spill, reservoir debris, and ice containment structures. In some of the earlier structures, limited design information resulted in cost ineffective structures, high maintenance costs, poor performance characteristics, and in some instances premature failure of the structure itself. Maintenance problems associated with floating structures under conditions of normal service should be determined. Additionally, techniques for repairing and extending the useful life of these structures should be investigated.

Steel Piling

The most common types of steel bearing piles, the H-pile and the pipe pile, are widely used in construction of hydraulic structures. Also, steel sheet piling has been extensively used for cellular retaining walls, cofferdams, cut-off walls, and bearing piles. Under some conditions, steel piling is subject to corrosion and rapid deterioration. The upper parts of piles embedded in relatively pervious soils are subject to corrosion by oxygen in humid air. Alkali soils and soils or groundwater contaminated by corrosive compounds from industrial wastes, piles of coal, or cinder fill may cause destructive deterioration to steel piles. Piles protruding into the air are subject to corrosion at the ground line by the action of surface water, organic topsoil, and air. In salt water and/or immediately above the mud line, deterioration may be fairly radid due to the abrasive action of water-borne sand in shallow water or to the presence of decaying organic or vegetable matter.

The effectiveness of steel sheet piling as a cut-off wall is subject to question because interlocked joints are not completely watertight, and because it is not unusual for a joint to open up during hard driving, thus destroying the continuity of the wall. When used as continuous bearing piles beneath concrete floodwalls, the steel sheet piling has, in some cases, apparently contributed to cracking in the concrete.

Evaluation, maintenance, and repair problems associated with steel piling should be examined to determine those areas which would benefit from research.

Repair and Rehabilitation

To date, research in concrete problem areas related to REMR has been largely governed by the squeaking wheel principle. Efforts have been directed at those problems which seemed to be the most severe as indicated by the Research Needs System. Due to the low levels of funding, the number of problem areas investigated has been small. While significant cost savings have certainly been generated by work done to date, there is no guarantee that the limited funding is being expended on the most critical long-term needs.

In an attempt to address this problem, work has been initiated on a review of existing inspection records for all Corps locks and dams. The first step was to compile a listing of locks and dams operated and maintained by the Corps. A total of 596 structures were identified and basic data concerning age, purpose, geometry, and location were obtained for each structure. The Periodic Inspection reports are currently being reviewed to develop input data for a computerized data base which will allow improved identification, examination, and evaluation of trends in deterioration and other problems in concrete structures. Once existing inspection reports have been reviewed and entered into the system, an analysis will be performed to determine the most prevalent types of problems and those which could benefit from research. Based on the limited research conducted to date, plus significant reimbursable work performed for the various Corps Divisions and Districts, and a review of the REMR Workshop, a number of problems relating to repair and rehabilitation have already been identified. The most significant problems are discussed in the following.

Concrete Erosion

A study by the U. S. Committe on Large Dams (1975) of the 4974 Federal and non-Federal dams higher than 45 ft noted 349 incidents

(7.0 percent) of unsatisfactory and/or unsafe performance, including 74 failures. The second highest cause (15 percent) of incidents involving dams constructed after 1930 was outlet works damage. Most of the damage was erosion of the concrete.

A survey of Corps Division and District offices in 1977 identified 52 structures that had experienced concrete damage due to erosion (McDonald 1980). The distribution of these structures is shown in Figure BII-9. Depths of erosion ranged from a few inches to approximately 10 ft. As an example of the latter case, nearly 2000 cu yd of concrete and bedrock was removed from the stilling basin of Dworshak Dam (Figure BII-10) due to erosion. Although the majority of erosion damage has been concentrated in stilling basins, other areas such as concrete channels, conduits, and lock emptying and filling laterals are also susceptible to damage of this type.

Approximately 65 percent of the structures identified in the survey have been repaired with the majority of these repairs being accomplished in the 1970's. Unfortunately, the state of the art in repair materials for erosion resistance left much to be desired during that period. Consequently, even though repairs were designed using the best available information, many have failed, often within relatively short periods of time. The Old River Control Structure and Kinzua Dam are good examples of this problem.

The stilling basin at Old River was inspected in August 1976 and found to be severely eroded in the area between the end sill wall and downstream row of baffles. Based on an exhaustive investigation and study, a plan to repair the basin with modules of steel plate anchored and grouted to the end sill and the basin floor slab was selected. Actual construction work on the repair was begun in September and completed in December 1976 at an estimated contract cost of $1,850,000.

An inspection of the repairs in August 1977 revealed that 7 of the 30 module plates and all 6 of the flat plates had sustained varying degrees of damage. All of the spoiler plates were missing. A second inspection in November 1978 revealed that additional steel plates had been ripped from the modules and minor erosion had occurred in the stilling

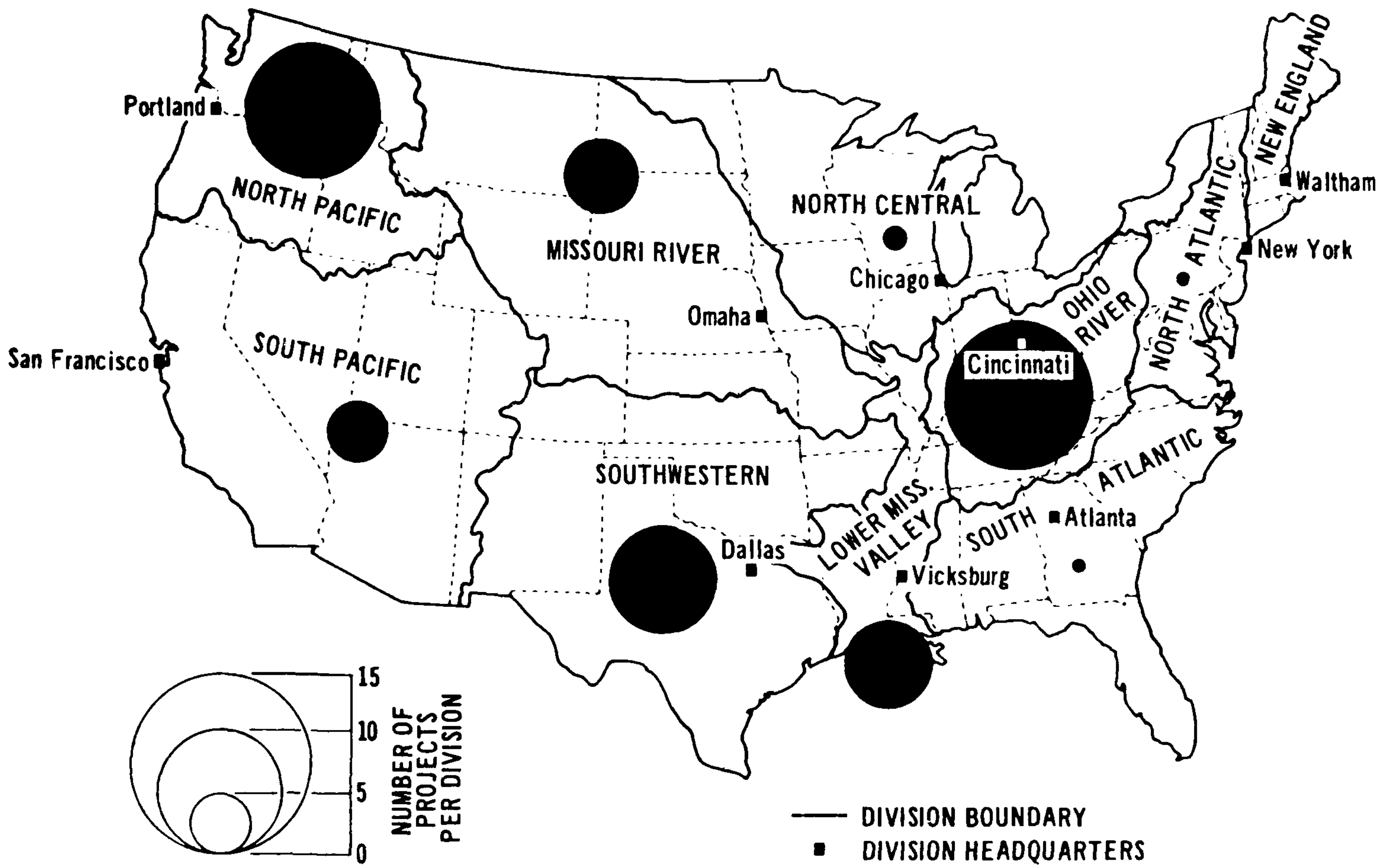


Figure BII-9. Number and distribution of structures which have experienced concrete damage due to abrasion-erosion

Figure BII-10. Typical damage to conventional concrete in the stilling basin, Dworshak Dam

basin slab upstream from the modules. At this point 16 of the 30 modules had sustained damage ranging from approximately 40 to 100 percent of the 1/2-in.-thick surface plate being ripped from the modules. In the fall of 1980, further repairs to replace eroded and spalled concrete on the surface of the stilling basin slab were accomplished.

Damage to the stilling basin floor slab at Kinzua was first reported in September 1969, less than 4 years after the structure had been placed in normal operation. By 1973, when a repair contract was awarded, concrete erosion had progressed to a maximum depth of about 42 in. The deeper holes in the basin floor slab were partly filled with conventional concrete prior to placement of a minimum 12-in. overlay of fiber-reinforced concrete. Total cost of the repair completed in October 1974 was $1,715,000.

In April 1975, concrete erosion ranging from 5 to 17 in. was noted in the fiber-reinforced overlay area. An inspection in June 1977 indicated concrete erosion to a maximum depth of 36 in. By October 1978, erosion in the concrete had progressed to a maximum depth of 42 in., the same as prior to repairs 4 years earlier. Currently, plans and specifications are being finalized to let a contract for repair of the stilling basin a second time. It is estimated that this repair will cost approximately $2,000,000.

The survey of erosion-damaged structures showed a definite need for laboratory evaluation of the erosion resistance of repair materials prior to their use in prototype repairs costing millions of dollars. Consequently, a new underwater abrasion-erosion test (Liu 1980) was developed, and a testing program initiated. Based on this work it was concluded that fiber-reinforced concrete should <u>not</u> be used for new construction or repair of stilling basins or other hydraulic structures where abrasion-erosion is of major concern. This guidance was furnished to Corps field offices in the form of an ETL.

The current limited research effort in this area should be expanded to include tremie concrete, preplaced aggregate concrete, surface treatments, and proprietary toppings with emphasis on construction materials suitable for underwater construction. Monitoring of the performance of various materials exposed in prototype structures should be continued. Results of laboratory and field tests should be used to develop engineering guidance for selection of materials to resist abrasion-erosion.

Cavitation-erosion results from cavities forming and collapsing in water flowing at high velocities. Pitting due to cavitation is readily recognized from the holes or pits formed, which are distinguished from the smoother worn-appearing surface caused by abrasion-erosion. Damage from cavitation is not common in open conduits at water velocities below 40 fps, however, concrete in closed conduits has been pitted by cavitation at velocities as low as 25 fps. At higher velocities the forces of cavitation are sufficient to erode away large quantities of high-quality concrete and to penetrate thick steel plates in a comparatively short time. Concrete in spillways and outlet works of many high head structures,

particularly hydro-power dams in the Pacific Northwest, has been severely damaged by forces of cavitation. For example, the outlets of Dworshak Dam sustained sufficient concrete damage within the first 4 years of operation to require repairs to approximately 410 sq yd of wall surface. The bid price for this 1975 repair totaled $176,718.

During recent years, evaluation of concrete subjected to high-velocity water flow with induced cavitation patterns was limited to tests of five concrete slabs (Houghton el al. 1978). These tests were performed to evaluate concrete proposed for use in the chutes and stilling basins of outlet works at Tarbela Dam, Pakistan. Based on results of this work and similar tests performed in the USSR, it would appear that polymer-impregnated concrete has higher cavitation resistance than conventional concrete. Significantly superior cavitation resistance was obtained by polymerization of a monomer-filled sand patch in one slab of conventional concrete. This technique, if similar results were obtained in a full-scale study, would be particularly applicable to repair of spillways and outlets which have sustained cavitation damage. Also, other special concretes and coatings such as polyurethane should be evaluated to provide guidance to the field in material selection and application techniques.

Dewatering

The majority of stilling basin repair operations require dewatering of the basin. In some cases it is extremely difficult and expensive to dewater a structure to make repairs under dry conditions. Libby Dam stilling basin was dewatered using a posttensioned concrete bulkhead (Figure BII-11) fabricated on site and floated into position above the end sill. In this case dewatering alone cost approximately $1,000,000 and resulted in some delay in the repair due to contractor problems with the bulkhead. A similar technique was used at Dworshak Dam at a cost of approximately $700,000. The steel cellular cofferdams used to dewater the stilling basin at Kinzua Dam cost approximately $734,000 out of the total repair contract of $1,700,000. In fact, a survey of erosion damage repairs indicates that dewatering alone averages over 40 percent of the total repair cost. One of the items that places maintenance

Figure BII-11. Prestressed concrete bulkhead in position, Libby Dam

activities involving lock closures in the forefront of the public eye is that such closures are generally restricted to low water seasons. This is the period of the year when the heaviest usage of the river system occurs. The capability to unwater and repair locks during high water periods could relieve some of the stress in public relations. Floating caissons similar to those used in the rehabilitation of Chief Joseph Dam appear to have potential in this application and should be investigated. The new stilling basin end walls added during repairs at Nolin are designed to support a bulkhead closure at the end of the basin. Also, a concrete equipment pad adjacent to the stilling basin will permit a mobile crane to place the closure for more expeditious dewatering. The potential for application of this and similar techniques to other structures including locks needs to be investigated. Studies should be performed to determine the optimum number and type of bulkheads that should be provided at each lock. These studies should be made along the lines of the relative cost effectiveness of having to provide floating

plant to unwater a particular valve or whether sufficient bulkheads need to be purchased so that valves can be unwatered without requiring floating plant.

Underwater Repairs

Because of the nature of the types of structures over which the Corps has responsibility, there is frequently a requirement to repair concrete which is underwater, close to the waterline, or in an area from which it is difficult to divert flow or dry the concrete. The repairs range from simple patching or sealing which may be accomplished by operations personnel to extremely complex underwater work accomplished by contract.

The more complex types of underwater work are considered first. The problems of abrasion-erosion damage to stilling basins and the high cost of dewatering such structures have been described above. The idea of repairing abrasion-erosion damage without dewatering a stilling basin using preplaced aggregate concrete or tremie concrete is very appealing. Even if the repairs are not as durable as those made in the dry, the savings may be great enough to offset the difference.

Some limited underwater repairs have been accomplished: Concrete was pumped underwater to fill small eroded areas in the stilling basin at Lock and Dam 26 on the Mississippi River and to perform the same type of repairs at the Old River Control Structure. Preplaced aggregate concrete was used to repair the stilling basin at Chief Joseph, while tremie concrete has been used at Ice Harbor and Webbers Falls Dams (McDonald 1980). While these applications have been generally successful, there are several significant problems and unanswered questions associated with underwater repair which must be resolved before the technique can be used on a routine basis.

The use of concrete placed underwater is quite common in new construction. These placements are usually for massive applications such as cofferdam seals or bridge piers. Some research has been accomplished in this area, and guidance for these massive placements is available (Gerwick, Holland, and Komendant 1981). The use of concrete placed underwater in relatively thin lifts is not a common practice in

construction since there has been very little call for such casting. But to repair abrasion-erosion damage without dewatering would require just this sort of placement. Specific guidance would be required covering several aspects of the overall repair procedure:

a. The first area requiring work is developing equipment and procedures to evaluate the existing surface of stilling basins and to provide accurate, detailed profiles of the damage. This information is necessary to allow for planning and estimating a repair and to allow for proper positioning of tremies during a placement. Work in this area is described elsewhere in this report. Research would be required to develop a suitable concrete mixture to be used for underwater repairs. The concrete mixtures used for typical, massive placements have high cement contents to insure proper flow and distribution during the placement. Research done to date (Liu 1980) has shown that higher cement contents are not necessarily associated with improved abrasion-erosion resistance. Lack of knowledge concerning the resistance of concrete placed underwater was one of the key factors in the decision to dewater the Kinzua stilling basin for its upcoming repair.

b. There is no current guidance available concerning proper equipment and procedures to be used when making small volume or thin placements underwater. Development of this information would be essential. There are several new concepts (placement techniques and admixtures) which may have some promise for placements of the type required. These would certainly have to be reviewed in detail before their use could be recommended for an actual structure.

c. There is currently no method to evaluate the integrity of the concrete placed underwater to determine if it will be adequate to serve its intended purpose other than by coring. Coring a large number of isolated placements as would be required to repair a stilling basin would become very expensive. This is an area in which there is potential for use of some of the nondestructive testing techniques mentioned elsewhere.

Overall, underwater repair of stilling basins appears to offer significant savings. Detailed guidance will have to be developed before these savings can be realized.

On the opposite end of the scale from the large repairs discussed above are the numerous minor problems such as spalling or erosion which occur to concrete in hydraulic structures. The problems toward which this is addressed are usually small enough in scope to be handled as maintenance by operations personnel or by District work crews.

The major problem associated with work of this nature is the lack of guidance covering both materials and techniques. Often, the only guidance available is from the manufacturer of a product. Billington (1979), referring to repair of concrete offshore oil structures, reported on evaluation tests of a large number of proprietary products which the manufacturers claimed were to be used underwater. The types of repairs he had in mind were precisely those which are important to the Corps hydraulic structures:

a. Sealing of cracks before injection.

b. Injection.

c. Priming the surface of concrete prior to patching.

d. Patching spalled concrete or filling voids.

e. Attaching bolts, dowels, or shear connectors into the concrete surface.

f. Bonding steel plates to concrete.

Of the numerous resin products tested, the vast majority failed to perform underwater as claimed by the manufacturers. This is the same problem faced by personnel in the Corps field offices responsible for selecting repair materials.

A comprehensive evaluation of products in this area needs to be conducted. A standard series of tests should be established, products obtained and tested, and results distributed throughout the Corps. Significant savings could result from repairs which perform as intended rather than failing during or shortly after application.

Another area which appears to offer the potential for savings is the use of precast concrete elements during underwater repairs or modifications. Precast concrete elements of very high quality can be manufactured before the repairs are made and then put into place when convenient. In addition to providing a high-quality concrete surface, the elements would serve as a form for grouting of any voids between the element and the damaged surface. The majority of this type of work could be accomplished without dewatering a structure.

One example of a modification using precast concrete was the addition of baffle blocks to a stilling basin in a small structure in the

Memphis District. Hydraulic studies conducted after the structure had been completed indicated that the blocks were necessary. Rather than dewater the structure and construct the blocks in place, precast blocks were used.

Similar to the use of precast concrete elements is the use of prefabricated steel elements for underwater repair. Flat plates were used during modifications to the end sill at the Old River Control Structure. Prefabricated steel armor units to slip over damaged baffle blocks have been proposed for use at Kinzua Dam.

For either the precast concrete or the steel elements, two areas of investigation are required: First, a better understanding of the situations in which such an approach to repair or modification may be economical needs to be developed. Second, the techniques used to attach or anchor the prefabricated elements need to be reviewed. Of the failures which have occurred, it has been the anchorages rather than the elements which have failed.

Finally, the question of monitoring the quality of repairs made underwater must be raised. To provide assurance that adequate quality is being achieved, techniques for underwater observation and sampling will be required. Requirements of underwater monitoring of repair work will have to be coordinated with work in the area of underwater survey techniques to insure maximum compatibility for both types of requirements.

Concrete Removal

Generally, the first step in any repair or rehabilitation procedure is removal of the deteriorated concrete. Traditionally, this was accomplished by impact methods which involve repeated striking of a structure with a mass to fracture and spall it. Recently, controlled blasting has been used for concrete removal on several projects. Blasting methods employ rapidly expanding gas(es) confined within a series of boreholes to produce controlled fracture and removal of the concrete. In general, blasting methods are efficient means of removing large volumes of distressed or deteriorated concrete. However, due to dangers inherent in handling and usage, these methods are considered the most dangerous and

require more stringent controls than any of the others. Planning a blasting project requires three basic areas of concern:

a. The safety of personnel involved and the general public.

b. Damage to adjacent structures.

c. Damage to the concrete that remains.

Although the contractor may be liable for these concerns, the Corps must implement controls that monitor and evaluate the performance of the blasting operation. In situations where explosive blasting cannot be used, an alternate means of removal must be selected. Techniques which appear to have potential as alternate means of removal include acetylene-air rock-breaker, concrete splitter, expansive agent, high-pressure carbon dioxide blaster, and high-pressure water jet (in situations where reinforcement is to be preserved for reuse). Also, a borehole notching technique appears to enhance the performance and crack control for some means of removal, such as explosive blasting and expansive agents, techniques that require boreholes.

A field comparison study should be made to evaluate selected techniques. Selection of removal methods for such a study would be made from those reported (Campbell 1982) to have potential as primary means of removal. It is felt that some of those having potential as secondary means of removal should also be evaluated. The study would be included as a part of scheduled repair and rehabilitation work at Corps projects. The principal determinations to be made for comparison would be:

a. Cost.

b. Removal rates.

c. Extent of damage to concrete that remains.

d. Problem areas.

The borehole notching technique should also be evaluated as a part of this study.

Concrete Repair Systems

There are many commercially available products for repairing concrete. Based on manufacturers' claims, there should be an existing product(s) suitable for any conceivable repair situation. Unfortunately, there are many examples where this has not proven to be the case.

In areas of the Dworshak Dam stilling basin where erosion of the original concrete had not progressed to the 15-in. minimum depth specified for the fibrous concrete topping, the design called for excavation of the remaining concrete to this depth. However, one section of the stilling basin floor (approximately 2160 sq ft) and the lower 20 ft of the spillway (2950 sq ft) exhibited only minimal erosion to a maximum depth of about 4 in., and the original reinforcing mat was not exposed. Therefore, it was decided to repair both sections with an epoxy mortar topping.

The epoxy work was completed using several types of epoxy mortar. The primary one was a stress-relieving material that was slow curing and had a low exotherm. This allowed mixing and placing in thick sections up to several inches deep without requiring layered systems. Several problems occurred with the epoxy during application that were primarily the result of workmanship, weather conditions, and failure to enclose the work area. Under the cool conditions that existed, the epoxy mortar probably did not fully cure before the stilling basin was put back into service. The original thought for using the epoxy was that it would be economical and fast, but this was not the case, and the quality of work was less than desired.

An inspection of the repairs 7 months later revealed that the epoxy mortar was failing. This area was filled with failures where the epoxy had broken loose at the concrete interface. An estimated 25 percent of the surface was gone. The epoxy failure areas ranged from a fraction of an inch deep up to 4 in. deep.

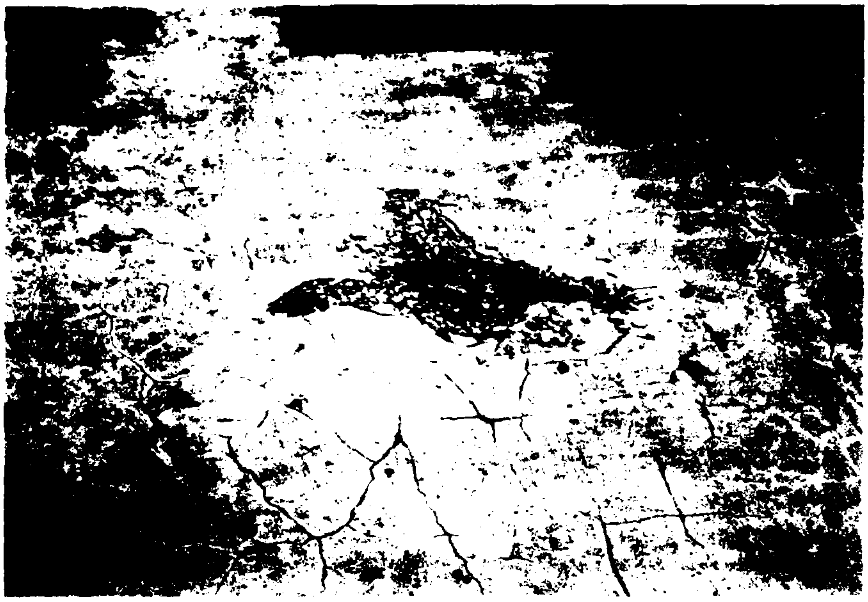
Moisture seepage through construction joints during repair operations is a continuing problem. At Pomona Dam the construction joint was saw cut about 2 in. deep and 1/8 in. wide. Fine sand was placed in the saw cut to serve as a drainage medium and 1/8-in.-diamter plastic tubes were positioned at 6-in. to 2-ft intervals to carry seepage from the joint. The area near the joint was air dried and a quick-setting, "moisture-compatible" epoxy was applied to the joint. However, several

small areas along the joint continued to develop leaks. Repeated patching of these areas was required before what was felt to be a satisfactory overlay was completed.

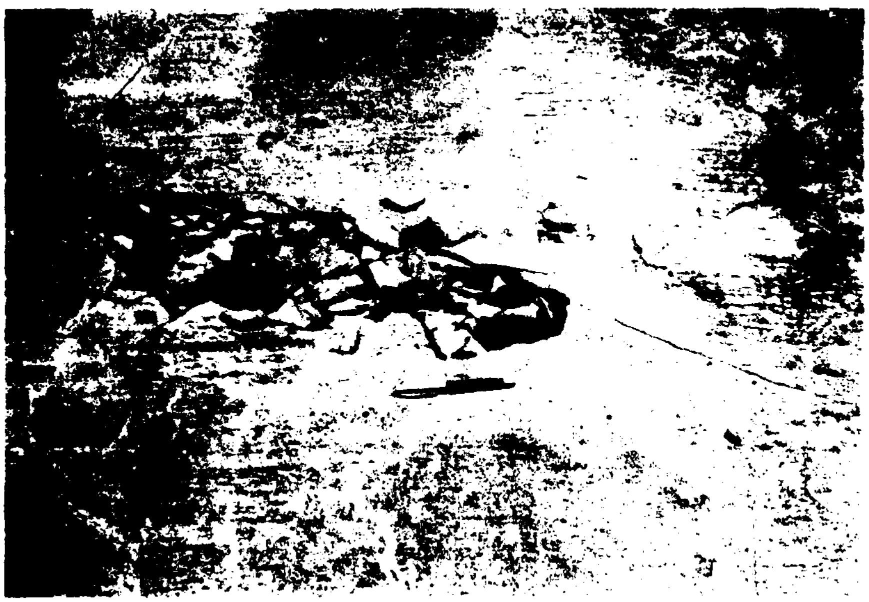
An inspection 4 years later showed that the epoxy mortar overlay had not suffered any visible erosion damage; however, cracks were observed in several areas. When pressure was applied to the cracked surface, moisture seeped up through the cracks indicating a lack of bond between the epoxy mortar and the concrete. Following removal of a section of the epoxy mortar it was observed that the failure plane was located within the concrete slab at depths up to 3/4 in. This type of failure indicates a thermal incompatibility between the concrete and the repair material. Similar problems occurred within months following application of a thin proprietary overlay on the top surface of the land wall at Lock 3, Monogahela River (Figure BII-12).

A similar problem occurred at Milford Lake where large portions of epoxy mortar on the floor of the tower water passageway failed. Tests at the Division Laboratory indicated that the epoxy mortar had a linear thermal expansion coefficient of approximately 17×10^{-6} in./in./^{o}F. This coefficient of linear expansion was approximately three times greater than the coefficient of linear expansion for concrete. Although temperature variations may only range about 30^{o} F, the difference in the thermal coefficients of the two materials may be responsible for the cracks. Other possible explanations for the cracks in the epoxy include: (a) properties of the epoxy mortar may change when it is submerged in water and (b) the ability of epoxy mortar to contract without cracking during temperature change decreases with age. An epoxy mortar used to repair piers at Lock and Dam 24, Mississippi River, which has failed due to thermal incompatibility with the original concrete is shown in Figure BII-13.

The concrete in the left stilling basin wall and outlet channel lining wall of Tom Jenkins Lake was badly deteriorated due to cycles of freezing and thawing (Figure BII-14a). Repairs were accomplished by hired labor in 1968 using a typical commercially available, prepackaged concrete mixture. The durability of the repair was certainly less than



a. General cracking and spalling



b. Closeup of buckled area

Figure BII 12. Failure of commercially available repair material

Figure BII-13. Failed epoxy mortar repair

desired (Figure BII-14b), having failed by the early 1970's. This illustrates the need for identification and evaluation of proprietary repair materials such that appropriate guidance regarding material selection can be furnished to the field.

Conventional portland cement shotcrete has been used to repair a variety of concrete structures with mixed results. Poor materials, poor workmanship, lack of surface preparation, and lack of entrained air in the shotcrete are a few of the problems which have resulted in poor quality work. The lock walls in the river chamber at Emsworth were refaced with shotcrete in 1959. Deterioration of the repair material has been obvious for many years and has progressed to the point (Figure BII-15a) where a complete refacing of the lock walls is again required. Spalling appears to have originated in the upper portion of the walls where the shotcrete was relatively thin and propagated down the wall to the point where the shotcrete thickness was sufficient to contain dowels and wire mesh (Figure BII-15b). Even in these areas, the shotcrete was

a. Deterioration of original concrete

b. Deterioration of repair concrete

Figure BII-14. Concrete deterioration due to cycles of freezing and thawing

a. General view

b. Closeup view of spalled concrete

Figure BII-15. Deterioration of conventional shotcrete repair

reported as "drummy" when sounded, and horizontal cores revealed extensive deterioration of the concrete immediately behind the shotcrete.

Many navigation locks do not have alternate barge-handling facilities and cannot tolerate extended closure for repair and rehabilitation other than the routine 2- or 3-week annual maintenance outage. Therefore, a variety of coatings have been proposed as expedient repairs on several structures.

Concrete surfaces on the original upper guide wall at Emsworth Locks and Dam were eroded to maximum depths of approximately 3 in. due to a combination of freezing and thawing, impact and abrasion by barges. A section of the wall was repaired in 1980 to demonstrate the use of steel fiber-reinforced shotcrete (fibercrete) in repair. However, after 3 months in service the fibercrete exhibited numerous examples of impact failure, abrasion erosion, and delamination. One possible explanation for the poor performance was that the prepackaged fibercrete mixture had a lower fiber and cement content than desirable. Fibercrete appears to have potential as a concrete repair material, however, it should be evaluated in the laboratory to determine material properties associated with optimum mixture proportions prior to use in the field.

Although a relatively new structure, the concrete in the walls of Lower Monumental Lock has an inadequate air-void system to resist damage due to freezing and thawing while critically saturated. In about 10 years it deteriorated to the point where surface scaling had exposed aggregates in the concrete. An essentially impermeable coating of latex-modified cement with fiberglass reinforcement was sprayed onto the lock walls to a thickness of about 3/8 in. The contract was completed in 18 days at a cost of $1.1 million. The estimated construction cost for conventional "remove and replace" repairs was $13 million in addition to the $13 million to provide alternate barge-handling facilities for a $26 million total cost (Schrader 1981).

If the concrete behind the coating never becomes critically saturated by migration of moisture from beneath or behind the lock walls, it is likely that this repair will be successful. However, if the repair material is in fact unable to permit passage of water through it from

beneath, the possibility exists that the concrete will be more fully saturated during future cycles of freezing and thawing. This would increase the potential for additional deterioration of the concrete behind the coating. A recent inspection of horizontal concrete cores from the Emsworth Lock walls confirmed this hypothesis. Cores from the river chamber show the relatively impermeable coating (i.e., shotcrete) to be in generally good condition, however, the original concrete behind the coating exhibits significant deterioration due to freezing and thawing (Figure BII-16). Cores of similar concrete from the land chamber which were not coated are in generally good condition from the surface inward.

While certainly desirable in terms of application time and cost, relatively impermeable coatings should not be adopted for repair of nonair-entrained concrete until it can be demonstrated by evaluation that such coatings have no long-term adverse effect on the concrete below the coating.

A major part of repair costs is due to the necessity for removing substantial portions of deteriorated concrete and replacing with new concrete. The concrete shown in Figure BII-17 is fairly typical of the condition of much of the concrete which is removed using current repair techniques. Materials and methods which would allow in situ treatment of such concrete without the necessity for removal should be investigated. The use of epoxy or other polymeric materials in such applications appears to have potential.

Impregnation/injection methods vary. Soaking monomer into concrete is one method. This is a gravity dependent method by which monomer is ponded on a concrete surface and the monomer allowed to seep or filter into the concrete under the forces of gravity. Once it is in place, it is either heat or radiation polymerized. It is effective for surface repairs, because the monomer has very little trouble saturating the surface pores of the concrete. However, the forces of gravity are not large enough to carry the monomer throughout the distressed structure and areas deep inside the concrete cannot be repaired in this manner.

Forcing monomer into the pore structure under pressure is another method of impregnation. This not only produces greater penetration of

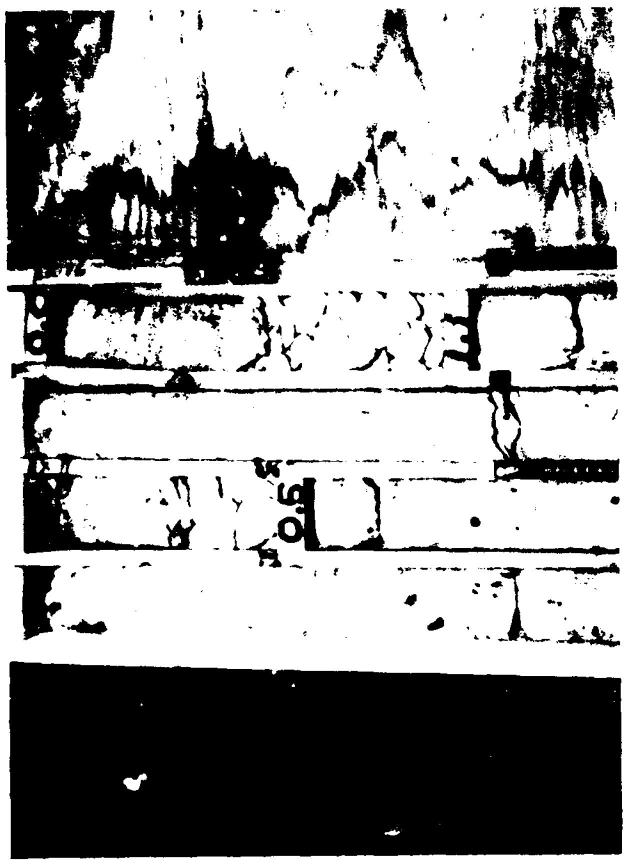


Figure BII-16. Example of concrete deterioration behind a relatively impermeable coating

Figure BII-17. Typical concrete core from structure deteriorated due to cycles of freezing and thawing

monomer into the distressed concrete, it also allows penetration on surfaces that are not compatible with the soak method such as vertical surfaces and underside surfaces of structures. Vacuum impregnation is a form of this type of pressure impregnation.

There are two major areas associated with this approach that need developmental attention:

a. Improvement in the methods by which a vacuum is applied to a structure. Present techniques are applicable to small structures or specimens. A vacuum is created by surrounding the structure with a nonporous membrane and evacuating the air from around the specimen, thereby drawing monomer into the voids where air had once been. This is difficult to control since large structures (bridge piers, etc.) are often of irregular shape and a vacuum would be difficult to hold. In addition, large areas of repair would require large sheets of nonporous membrane. One approach that should be investigated would be to drill one or several boreholes into the structure and create a vacuum from beneath the surface. This would negate the need for a vacuum to be formed at the surface and negate the need to surround the structure with a large nonporous membrane. Portions of the structure could be worked at a time and all that would be necessary at the surface would be a dam to hold the monomer. Grouting of the drilled holes could repair the surface.

b. The majority of the monomers that are available for impregnation purposes are too viscous to achieve good penetration depths. Those that can penetrate often do not achieve full polymerization upon treatment. The problem of high viscosity means that the monomer will not penetrate into small cracks and voids and causes the use of heavier vacuum pumps than should be needed. Polymerization techniques, either by radiation or heat treatment, do not always reach the monomer in the heart of the specimen or structure and consequently leave some of the monomer unpolymerized and without any of the strength characteristics of the polymer materials. Combinations of monomers that have low viscosity with those that have good polymerization characteristics will produce hybrid monomers that will achieve high degrees of penetration and good percentages of polymerization. New techniques of polymerization need to be developed to assist in overcoming this drawback.

The benefits of this work would include effective techniques of repairing and improving concrete structures at lower costs and producing more durable surfaces. This technique appears particularly applicable to repair of gate piers such as those shown in Figure BII-18. Materials

a. Cracking in top surface of gate pier which allows ingress of moisture and accelerates deterioration

b. General view of concrete deterioration

Figure BII-18. Typical deterioration of tainter gate piers, Montgomery Dam

and techniques developed would allow deep impregnation of large field structures with a minimum of labor, materials, and difficulties.

The potential savings inherent in construction using precast concrete are well documented. For example, the low bid for construction of the Park River tunnel utilized a precast liner and was approximately $3 million below the low bid for the closer of the other two bid options. However, precast concrete has been used only to a very limited degree in concrete repair due primarily to the difficulty in handling and installing unusual sizes, shapes, and types of concrete in particular applications. The intimate contact of fresh concrete used for cast-in-place repairs has been considered better for repair. In most cases, however, precast concrete can be superior to cast-in-place concrete and therefore the use of precast should be considered for applications where a specialized concrete is needed. Design criteria, design methods, practical joint configurations, construction tolerances, etc., which have been developed in connection with new construction should be reviewed and analyzed for potential applications in repair and rehabilitation.

Roller-compacted concrete or lean rolled concrete, as it is sometimes called, involves the use of a dry concrete mixture consolidated by vibratory rollers. The structure in which it is placed may be built up by a single layer of concrete, as in the case of pavements, or in multiple layers, as in the case of dams, foundations, and other mass concrete works. The concrete as placed must be dry enough to support the weight of the vibratory roller and yet not so dry as would prevent the cement paste from being uniformly distributed throughout the mass.

Roller-compacted concrete has already been used on a couple of construction jobs in the United States, and for the upstream cofferdam for the Okawa Dam in Japan. But, undoubtedly, the most extensive use to date has been in Pakistan, where early in 1975 about 344,000 m^3 of concrete were placed in Tarbela Dam project to replace rock and embankment sections washed away in the collapse of an outlet tunnel. It is, indeed, significant that this huge quantity of concrete was placed in just 44 days with a peak placement of 19,000 m^3 in a day. It is also revealing

that for a dam project in the United States, the preliminary investigation has shown a cost advantage of at least 10 percent in favor of roller-compacted concrete compared to an earthfill design. These facts are indicative of the potentialities that exist for this new technique.

Rehabilitation of Navigation Locks

More than half of the Corps' 260 lock chambers are over 40 years old. Many of these older structures are currently in need of extensive rehabilitation; others will require repair and rehabilitation in the near future. Renovation of a navigation lock typically costs between \$10 million and \$30 million. Obviously, in a rehabilitation program which could ultimately cost \$2 to 5 billion there is a need for evaluation and development of materials and techniques to insure optimum utilization of available resources. Limited work in this area is already paying significant dividends. For example, since there was no engineering guidance available to establish a requirement for the number and spacing of dowels required to anchor replacement concrete to existing lock faces, therefore the various Districts involved selected conservative spacings which resulted in the use of large numbers of dowels. Typically, in excess of 10,000 dowels were being used in a rehabilitation project. Installation of the dowels is very labor intensive and, therefore, very expensive.

Liu and Holland (1981) showed that bond of the replacement concrete played a much more significant role than the dowels in anchoring the replacement concrete. Therefore, the number of dowels could be significantly reduced without affecting the integrity of the repair. Based on the initial results of this work, a rational procedure for selecting dowel spacing was developed and furnished to the field in Engineer Technical Letter 1110-2-264 (OCE 1981). Implementation of these criteria typically results in 75 percent fewer dowels being used at a savings of more than \$250,000 per project. Assuming that all of the locks over 40 years of age will ultimately require rehabilitation, this should result in a savings in excess of \$30 million.

Criteria for dowel spacing are based upon a shear-friction mechanism, therefore, the importance of adequate surface preparation of the

old concrete in order to develop this mechanism is emphasized. Also, the importance of a good bond between the old and new concretes must not be overlooked. The use of epoxies or other bond-enhancing agents for lock wall renovation should be investigated. Also, the long-term bond performance of replacement concrete under extended weathering and under freezing and thawing conditions should be investigated.

Current field guidance is based upon a hooked dowel being used in the replacement concrete. It appears that a variety of anchorage schemes are being used in actual applications; e.g., flat plates welded on the end of dowels, straight dowels without hooks, and proprietary devices. In order for the shear-friction theory to perform as intended, the full development of the dowel in the replacement concrete must be achieved. An investigation of the various dowel types being used is required to insure that proper development is being achieved.

The general approach in rehabilitation projects has been to treat the project as new work. Procedures followed for concrete operations have been those with which contractors and inspectors are familiar from past experience on new work. However, there is increasing evidence that rehabilitation work is often much more complex and that normal new construction procedures often do not produce satisfactory results in rehabilitation work. For example, significant cracking has occurred in the replacement concrete on all lock rehabilitation projects to date. At Lock and Dam No. 1 on the Mississippi River, cracking (Figure B11-19) persisted despite various attempts to eliminate it. These cracks, which generally extend completely through the 12- to 18-in. thickness of replacement concrete, are attributed primarily to restraint of volume changes resulting from improper temperature control, inadequate prevention of drying shrinkage, and autogenous volume changes. All of these produce additive effects and must ultimately be considered together.

In many cases the restraint conditions are more severe in replacement concrete than in the original construction. Therefore, based upon experiences to date, cracking can be expected to continue in replacement concrete during repair and rehabilitation efforts. Also, because of the smaller volumes of concrete involved, recognition of problems beforehand,

a. General view

b. Closeup view

Figure B11-19. Cracking in replacement concrete on lock wall

concrete during repair and rehabilitation efforts. Also, because of the smaller volumes of concrete involved, recognition of problems beforehand, especially those of thermal origin, may not occur. At Lock and Dam No. 1, cracking was observed as early as 1 day after placement of the resurfacing overlay. Corrective efforts included use of expansive cement and inclusion of control joints. Some improvement was observed; however, the problem was not eliminated. These efforts are predominantly trial and error solutions that even if successful in one case do not ensure an understanding of the causes of cracking in the first place, nor will they necessarily be successful in other applications.

In most cases the results of cracking occurring in replacement concrete will not cause structural deficiencies. However, the rate of deterioration of the repair efforts will be hastened, become unsightly, and will require additional and reoccurring maintenance. Guidance must be developed on first of all how to avoid or minimize such cracking, then once it happens, when do you repair (maximum permissible crack width), and how do you repair? Such guidance is needed to insure the durability of the repair as well as the underlying concrete.

Concrete Exposed to Aggressive Water

Degradation of concrete due to attack by aggressive or acidic water has been reported at several Corps structures. Raystown Dam (Baltimore District) suffered extensive damage to spillway training walls and floor as well as to an outlet tunnel due to cement leaching by aggressive water (Holland et al. 1980). Holt Lock and Dam (Mobile District) suffered damage to exposed concrete through exposure to acidic water. Surface concrete in the outlet tunnels at Piedmont Lake and Clendening Lake (Huntington District) was reduced to a "mush" consistency due to acid attack in a corrosive process caused by sulfur bacteria action (Thornton 1978).

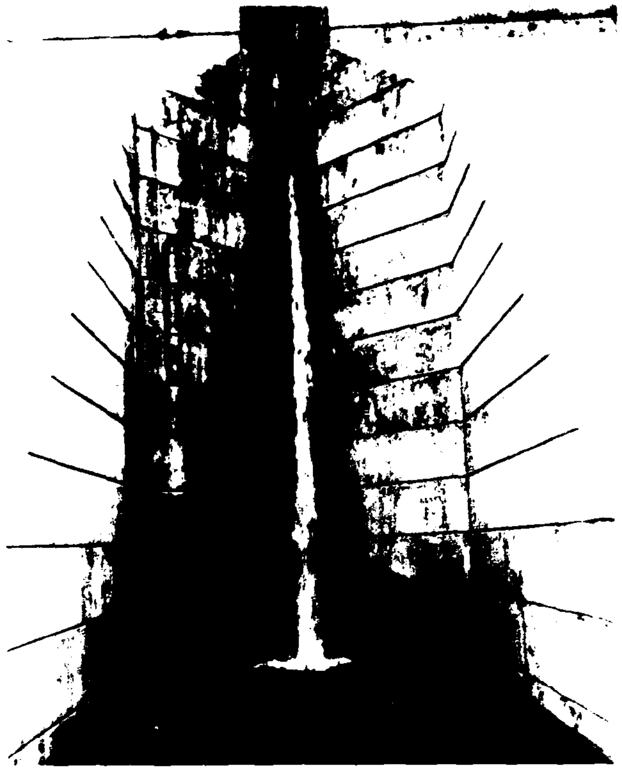
At present, there is little guidance available concerning repair techniques and materials for concretes exposed to aggressive waters. There are a wide variety of proprietary products available, however, their performance in severe exposure is usually unknown.

Research, as such, is not actually required. What is required is testing of these proprietary products to establish the level of performance which could be expected. Products which perform poorly or which are complex or difficult to work with could be eliminated and a list of approved products could be provided to the field.

Waterstop Failures

The principal function of a waterstop is to prevent the passage of water through a monolith joint. Effective monolith joint waterstops are necessary in dams, powerhouses, navigation locks, and other structures. A failure of the waterstop can result in various problems ranging from minor leakage with cosmetic concern to major hydraulic forces and structural overloading. An extreme problem might cause indirect tensile stresses in the concrete mass and overloading of abutments, the foundation, and adjacent monoliths. Serious, but nonstructural problems can also occur, e.g., leakage can flood critical areas such as the galleries and transformers on the downstream side of a monolith joint. Less serious structural problems include esthetics and the public's opinion of the "leaking" dam. A number of structures have experienced waterstop failures (Figure B11-20) due to improper installation, deterioration with age, improper design for actual service conditions, or service conditions not normal to the structure. Tilting of navigation lock monoliths has caused rupturing of waterstops between individual monoliths in a number of structures. When the Little Goose Lock chamber was filled, water leaking through a failed waterstop spilled knee-deep into an adjacent parking area. In addition, leakage through fill adjacent to the lock removed fines resulting in settlement of small structures and utilities constructed on the fill. Also, there have been cases where waterstops were omitted during construction. In any case, failure of a waterstop allows water to pass through the joint into areas that are supposed to remain dry. If the problem is allowed to continue, water passing through the joint may erode the supporting soil and cause a subsequent foundation failure, with possible loss of the entire structure.

Normally, waterstops are located several feet back from the concrete face which practically prohibits access to the waterstop in any



a. Little Goose Lock and Dam

[illegible] Dam

Figure BII-20. Joint leakage [illegible]

repair/replacement operation. In some cases attempts have been made to install replacement waterstops along the concrete face. These include installation of keeper-plate clamped rubber type waterstops (John Day Lock) and sawed joints with sealant (Lower Monumental Lock). However, structural conditions in many monoliths require replacement of waterstops as originally constructed. In this case, attempts are made to drill holes along the joint to allow installation of replacement waterstop. Obviously, maintaining relatively small diameter drill holes along a joint, particularly for extended depths, can present significant problems. Once drilling was completed, several materials and techniques have been used in attempts to seal the hole. A reinforced plastic firehose was used as a liner for the boring at Little Goose Lock. Initially, the firehose was filled with water and pressurized to 10 psi using air. Eventually, a small hole developed in the hose requiring considerable maintenance to keep the waterstop effective. Materials such as bentonite slurry, cement grouts, chemical grouts, burlap bags saturated with chemical grout, closed-cell foams, etc., have been used in attempts to press a variety of tubular materials against the walls of the drill hole with sufficient pressure to prevent seepage. Obviously, many different techniques have been attempted in the past to repair/replace leaking waterstops. For the most part, they were unsuccessful and required significant maintenance. Basic repair/replacement materials and techniques should be developed which can be adapted to a wide variety of construction situations.

Joint Deterioration

While the nonair-entrained concrete in many of the Corps older structures is in relatively good condition after 40 to 50 years in service, one exception is the concrete around monolith joints (Figure BII-21). Deterioration along monolith joints due to difficulty in consolidating the concrete in these areas during construction, freezing of water in the joint, barge impact, etc., is generally more severe than in most other areas of all lock structures. Concrete deterioration along joints is also a problem common to many other structures including

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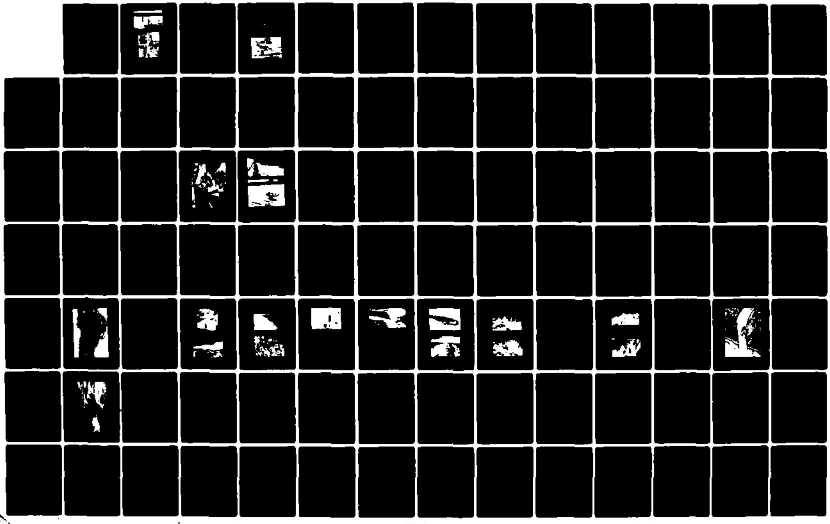
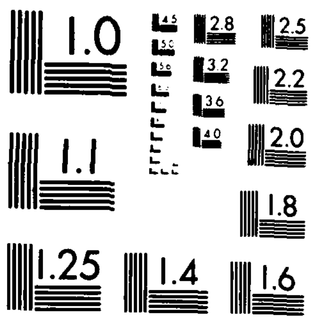
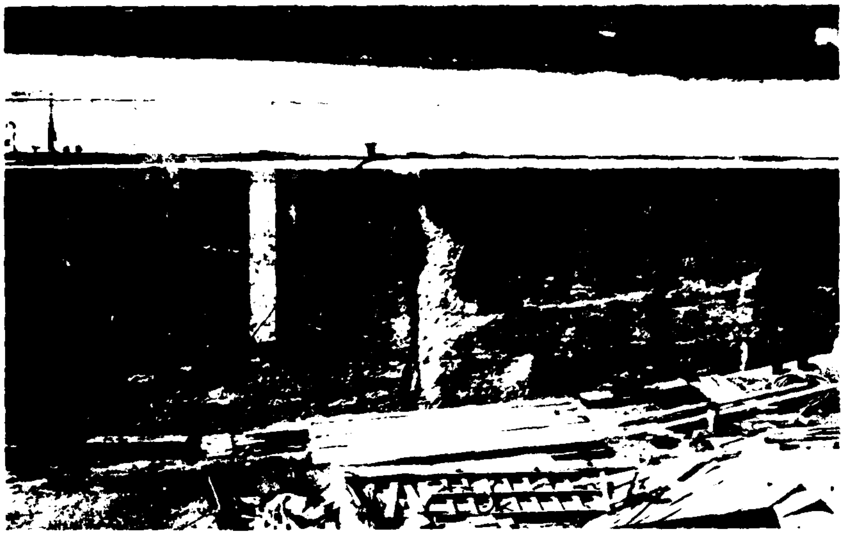






a. Overall view

b. Closeup view

Figure BII-21. Typical concrete deterioration along monolith joint

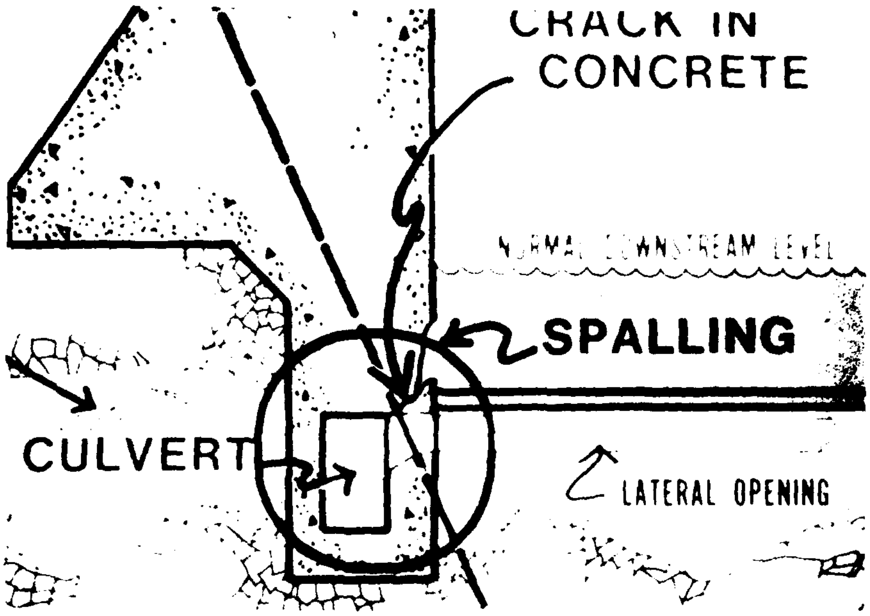
retaining walls, conduits, spillways, and intake towers. There is a definite need for a proven system to maintain/repair monolith joints in an expedient manner.

Structural Stability

Quite frequently the evaluation of an older structure indicates that the structures does not meet present stability criteria for sliding or overturning. While there is obviously a question of whether, in all cases, it is necessary for an existing structure to meet criteria established for new construction, there are many cases in which the stability of an existing structure must be improved to provide adequate safety factors. Usually, the method selected to increase stability is to posttension the structure to the underlying foundation materials. Posttensioning, whether done with tendons or bars, is a specialized and expensive process. The inherent difficulty of the process is often increased due to the lack of valid as-built drawings for many of the older structures. The posttensioning tendons or bars are often susceptible to corrosion and may become a maintenance or replacement problem in future years. Also, posttensioning creates additional stress in the concrete which is undesirable in many cases.

A review of techniques for increasing structural stability needs to be accomplished. The goal of the study would be to develop techniques which could be used in lieu of posttensioning and which would be more economical considered over the estimated remaining life of the structure.

Rock anchors of various types have been used in repair and rehabilitation of a number of locks and dams. During a 1975 inspection of John Day Lock, significant structural cracking and associated spalling was discovered in two lock monoliths. By 1979 cracking and spalling had been detected in a total of six monoliths. Structural distress in the monoliths consisted of a crack that originated at and propagated from the upper inside corner of the filling and emptying culvert and terminated at the structure of the wall in the lock chamber (Figure BII-22). Repairs consisted of (a) grouting the foundation rock, (b) installing rock anchors in drill holes through the crack plane after injecting structural



a. Crack location

b. Concrete spalling associated with cracking

Figure BII-22. Lock wall cracking and spalling

epoxy adhesive into the cracks, and (c) repairing the surface of the lock chamber wall. Posttensioning systems and rock anchors have also been used in crack repair on a number of other Corps structures including Ice Harbor, Gallapolis, Greenup, Marmet, Markland, London, and Winfield Locks. A wide range of anchor types, drilling techniques, anchor installation procedures, grout mixtures and injection techniques, stress equipment and protection systems have been utilized. Since anchor systems of some type are required on almost all rehabilitation projects, previous work should be reviewed to identify those techniques which have been most successful for application in future work.

Concrete Bridge Decks

The deterioration of concrete bridge decks and other highway-type structures is one of the most severe problems facing the highway industry today. Deterioration is specially serious in bridge decks in areas of North America where deicing chemicals are used in winter maintenance operations. The salt penetrates the concrete and initiates corrosion of the steel reinforcement. This in turn causes cracking and rupturing of the concrete and spalling of the concrete surface. In addition, some older bridge decks, built to lower standards of quality than modern structures and constructed without the benefit of efficient waterproofing systems and air entrainment, suffer a more deep-seated distress as the concrete progressively disintegrates from the surface downward under freezing and thawing action.

The Corps is responsible for maintenance of approximately 300 highway bridges across waterways and dams as well as service bridges associated with many Civil Works projects. Recently, several of these bridges have required rehabilitation as discussed in the following.

Over the years, the Chesapeake City Bridge was patched at an ever increasing rate, until well over 2000 patches of every sort had been installed (Mele 1981). Deck sealants were also tried but with no success. Conditions finally reached the point where a safe riding surface could not be maintained requiring complete replacement of the concrete deck in 1978 at a contract cost of $3,640,042. Similar problems with the Corps-operated Bourne Bridge across the Cape Cod Canal resulted in a

rehabilitation contract award in 1979 for $11 million, of which $7 million was bid as deck replacement costs. An almost identical repair of a second bridge across the Cape Cod Canal was initiated in 1981. Plans are currently being finalized to replace the concrete bridge deck across the spillway at Dale Hollow Dam.

The tremendous costs associated with replacement of concrete bridge decks are obvious from the above examples. Therefore, it is imperative that the Corps develop appropriate maintenance and repair systems to minimize requirements for complete rehabilitation. Also, where rehabilitation is required, alternatives to complete removal and replacement of the deck should be developed.

Lock Gates

At Greenup Locks, a 1/4-in.-diameter black iron pipe was specified for grease piping on the miter gates. After 15 years of service, the pipe corroded away preventing grease from getting into the pintle assembly. The pintle bushing seized with the pintle ball due to lack of grease, and the pintle shoe rotating with the leaf on the embedded pintle base resulted in major damage to pintle assembly components and quoin bearing blocks.

At Gallipolis Locks, frequent tow damage followed by often less than adequate field repairs resulted in horizontal and vertical leaf misalignments with inaccurate controlling dimensions. As a result, the vertically framed leaves could not function as designed. Consequently, bearing and wearing failure of pintle bushings occurred caused by impact and hydraulic loads.

After 21 years in service, a diver inspection of the miter gates at New Cumberland Locks found cracks in the structural members near the pintle casting. The divers, upon a closer inspection, also noted cracks between the end diaphragm flanges and webs at the lower two or three horizontal beams. The critical nature of the situation led to a decision for immediate closing of the lock to determine the extent of the problem, perform remedial measures necessary to resume lock operation and investigate possible causes.

A comprehensive inspection of the gate leaf revealed scarifications on the quoin block, cracked welds at the joints between the end section flanges and the quoin block bearing plate, and cracked welds between the end section flanges and the quoin girder at the four bottom girders. Also, the weld between the end diaphragm plate and the bottom web plate was cracked in the vicinity of the quoin block bearing plate. A detailed inspection of the pintle showed circumferential markings in the grease on the chamber side and in the swing zone of the gate leaf with a similar pattern also noted on the bronze bushing. Problems of binding at the quoin blocks were also found by divers at Pike Island, Hannibal, and Maxwell Locks.

Surveillance and Monitoring

Surveillance and monitoring involves people, observation, instrumentation, and evaluation. An effective structure surveillance program requires qualified personnel to know what to look for and how to evaluate what they have observed. It also requires instrument observations from monitoring systems.

Training is necessary to have well qualified field engineers to perform inspections and evaluations on a periodic basis. In addition to formalized training courses, one training objective should be to provide for rotation of personnel, through design and field inspection assignments, so that any individual on responsible assignment should be capable of understanding and evaluating the importance of visual observations and instrument data. Further, personnel who have responsibility for making decisions on a project have to be ready to take appropriate and timely corrective measures as needed.

Structure monitoring systems and devices serve the purposes of assessing the adequacy of design and providing indications of adverse performance. The latter is of primary importance, because it directly affects the public safety and welfare. In response to a directive in a memorandum from the President, dated 23 April 1977, the Corps reviewed and assessed its practices in dam design and construction as they relate

to public safety. Though not formally stated, safety has always been the keystone of the Civil Works program. The June 1976 Teton Dam failure stimulated the Corps to review its practices in dam design. The results of that earlier review, as well as the results from other internal and external reviews were integrated into the Presidentially directed review.[3] One of the areas found to need attention and improvement was analysis of instrumentation data.

Statistically, a catastrophic dam failure causes between $1,500 and $178,000 worth of residential propery damage per acre-foot of reservoir, along with 0.4 to 45 deaths per acre-foot in cases where the downstream area is not evacuated. As an example of a recent dam failure, the June 1976 collapse of the Teton Dam in Idaho resulted in 11 deaths and caused an estimated $400 million to $1 billion in property damages (Smith and McAllister 1979).

<u>Automatic Monitoring Systems</u>

The potential for destruction resulting from a dam failure has created significant interest in the development of instrumentation capable of automatically monitoring a large dam and providing advance warning of a failure. Given enough time, the dam structure could be repaired and stabilized, the water level of the reservoir lowered, or the people and property below the dam evacuated.

At present there are several methods used to monitor the behavior of concrete gravity dams. During their construction, instrumentation is generally embedded in the structure. This allows measurement of temperatures and stresses in the concrete and joints of the dam. Plumbbobs and inclinometers in the dam measure any tilting of the structure. Piezometers and stress meters installed under the dam detect water seepage and show the interaction between the dam and its foundation. Data from these and other types of available instrumentation should be used to provide an automatic and timely diagnosis of any abnormal behavior of a structure. The main objective of such a system would be to monitor a structure for 24 hours a day through:

<u>a</u>. Collection of measured data following pre-established schedules.

<u>b</u>. Analysis of collected measurements using simple models.

c. Calculation of the theoretical measurement values and comparison with corresponding observed values.

d. Calculation of differences between computed and observed values.

e. Comparison of differences with the amplitude of the tolerance bands.

f. Issue of appropriate warning in case such differences fall outside the tolerance bands.

g. Filing of data, as they are collected and generated, for off-line activities.

In some cases, instrumentation of the types described above cannot be easily installed in dams whose construction has been completed and the older dams among these are the ones most likely to need monitoring. Another method to monitor dam behavior is to establish stable observation piers in a pattern downstream of the dam and use precision surveying techniques to measure the displacements of targets placed on the dam surface. Using many observations and triangulating between observation piers and targets, the position of a target may be determined within a few millimetres. A survey of this sort is time-consuming, however, and expensive because of the experienced crew needed to set up the instruments and take the measurements. Also, the remote location of many dams makes frequent surveys unfeasible. In light of these problems and the desire for an automated monitoring system, manual surveying is not deemed a suitable method.

Considering the expanding use of highly accurate laser distance meters in surveying applications and the ease with which many computers can be configured and programmed to control a large range of devices, a dam monitoring system employing distance measurement appears feasible. The theoretical accuracy of the system appears sufficient to suit the requirements for measuring dam motion and its cost would not be large compared to the potential savings in property and life if a dam failure is prevented. A prototype system should be constructed and tested in an actual monitoring environment to determine its worth as a dam motion monitor.

Data Collection and Analysis

The Corps at present maintains 536 operating dams with ages ranging up to 145 years, and a variety of instrumentation devices plays a principal role in assuring their continued safe performance. Typically throughout the Corps, the most widely used types of instruments can be placed in any one of the following general categories: (a) water pressure measurement devices, (b) strain devices, (c) equipment for measuring seepage volumes, (d) devices and procedures for measuring movement, (e) instruments for measuring earth pressures, and (f) seismic monitoring devices. Readings from these devices are made at systematic intervals, usually once a month, by operating personnel and are supplied to the District office for interpretation, evaluation, and analysis. In addition, overall performance of the structure is reviewed at regular intervals (from 1 to 5 years depending on age and operating history), by a formal inspection on site by a multidisciplined team from the responsible field office. In this way, the combined talent of experienced design and operating personnel can be applied effectively to the evaluation of structural behaviour and safety-related maintenance can be given high priority. Similar inspections are also made during the initial reservoir filling and periods of higher reservoir stages, at which time the instrumentation reading schedule is shortened to a daily basis. Considering that a major dam may have 1500 to 2000 instruments, the magnitude of the data collection, reduction, and analysis problem is obvious.

In recent years, the great advances made in the field of instrumentation and automatic data processing have opened up new possibilities for systematic collection and interpretation of a variety of measurements. Automatic data acquisition systems and microcomputers appear particularly applicable for real-time collection, processing, and storage of measurement data. Such equipment should be investigated to determine its potential in monitoring and surveillance of Corps structures.

Improved Instrumentation for Older Structures

Older structures, by virtue of the length of time they have been in existence and the opportunities that they have had for conditions to

change from what was conceived in the design scheme, are subject to have lower safety conditions than new structures. One only needs to consult the results of the Periodic Inspections conducted on the Corps' older structures to see that loading conditions have changed, concrete has deteriorated and cracked, seepage conditions have changed, bearing areas beneath lock monoliths have reduced, or monoliths have been displaced from their original locations. The instrumentation that we use to monitor most of these conditions is old and outdated. In many cases Districts have complained that the instruments have failed and no longer give readings, this happening just when increased monitoring of a particular condition may be needed.

The technology in instrumentation has progressed logarithmically in the past two decades. Techniques for measurement of engineering structures have become quite sophisticated and accurate using electronics, lasers, vibration technology; much of this has been applied to monitoring of structures but the word has not been spread as far as it should and the technology has not been applied to all the conditions where it would be applicable.

Outmoded means of instrumenting structures, or not instrumenting them at all, can lead to adverse conditions that appear without warning. This situation at the least is inconvenient, causing repair dollars to be spent that may have been saved if the condition causing the needed repair had been known at an earlier time. At the worst case catastrophic failures could occur that carry price tags not measured in dollars.

Complaints have been made that instruments cease to function after a while. Then, it seems that the instruments designed for embedment must be made more durable or located in a less vulnerable area. More durability generally means more cost; however, alternate means of protecting instrumentation need not be overly expensive, just thorough and well put together. Location in less vulnerable areas seems to be a good means of increasing potential lifespan, however, care must be taken to insure that adequate input data will be received from such a location.

Analysis of the conditions that are causing instrument failure should be undertaken in order to improve the instrument's design.

Alternative methods of making the same measurement, such as using trilateration instrumentation to measure dam face movement rather than plumb line instrumentation removes the instrument from the structure where it can be treated in a manner that will promote extended life. New applications for existing instrumentation should be investigated. And finally, development of new instrumentation either to replace more vulnerable ones or to answer questions not otherwise addressed will improve the information received from structural instrumentation of older structures.

Field Inspection of Structures

With increased emphasis being placed on the repair and rehabilitation of existing concrete structures, it follows that the earlier we detect the problem, the more effective will be the remedy from an economical and operational standpoint. Current inspection techniques rely heavily on visual examination. If visual examination of the concrete surface indicates possible problems, a more detailed evaluation of those specific parts of the structure is generally in order. In most cases this involves coring of the concrete which is time-consuming, costly, and destructive. The use of available nondestructive methods is often limited in scope and reveals nothing about the in situ performance capability of the structure.

It is desirable that structures be evaluated in-place, nondestructively, and in real-time for general condition and structural integrity. Resonance techniques have been used in the laboratory for years to determine the integrity/deterioration of small concrete specimens subjected to accelerated freezing and thawing. With the advent of new computerized equipment that permits fast Fourier analysis on site, in real time, the feasibility of using this technique for inspection of large field structures is being studied. Laboratory tests indicated that the dynamic modulus of elasticity (a measure of concrete integrity) could be calculated for large rectangular blocks that were unrestrained at the base by measuring the fundamental resonant frequency of vibration. Previously, excitation had to be accomplished with large electro-hydraulic equipment to determine fundamental resonant frequencies. Later, a frame and various

hammers were fabricated that permit swinging a large 1000-lb weight through a small arc to generate a single load pulse to excite a structure into free vibration. An accelerometer is placed at a point of maximum vibration and the fundamental resonant frequency determined. Results of limited field tests of this technique at Lake Superior Compensating Dam and Richard Russell Dam appear promising. Structure frequency and damping changes with different foundation materials. Also, changes in frequency and damping have been observed when the structure is cracked. Because the vibration parameters are a function of modulus, boundary restraints, continuity (mechanical properties of the structure), it is natural to make use of the vibration technique to evaluate the integrity/deterioration of a large concrete structure. Using the impact-resonance technique, the characteristic vibrational signature of a structure may be evaluated at selected time intervals to supplement periodic inspections and in an effort to predict service life.

PART III: GEOTECHNICAL--SOILS SUBAREA

Problem Identification

The problems identified by the Division offices revealed a broad spectrum of needs related to soil features of existing Civil Works projects. These include problems associated with reservoirs and channels, earth and earth-supported structures, and auxiliary facilities such as project access roads, switchyards, and drainage structures. The soil and related problems of highest concern, along with the user needs, are listed in Table BIII-1 under the following categories:

a. Problems reflecting needs for remedial improvements.

b. Problems which involve evaluation of soil conditions and/or of performance.

c. Problems associated with maintenance of soil featudes.

The problems of highest concern will be addressed to the maximum extent possible in the research program. Other problems of lesser immediate concern are worthy of an expanded R&D effort to accrue technical and economic benefits; these are also discussed hereinafter, though not listed in Table BIII-1.

Problem Characteristics

The problems identified by the Division offices were generally project-specific. While they reflected local problems, similar or related problems were often reported by several offices. Other Corps Divisions have similar problems or needs that would benefit from solutions to certain problems. An in-depth survey would reveal that many of these problems have Corps-wide relevance or at least exist in the geographical areas of more Divisions though differing in the degree of severity and frequency, site conditions, and other distinguishing variables.

Problems arise in embankments and appurtenant structures either externally (e.g., dispersive clay tunnels) or, more seriously, internally (e.g., clogged or deteriorated drains). Foundations for embankments

Table BIII-1

REMR Soils Problems Identified by Division Offices, R&D Laboratories, and OCE

Problem	User Needs
Remedial Improvements	
1. REHABILITATION ALTERNATIVES TO CONTROL LEVEE UNDERSEEPAGE	
a. Underseepage and seepage through levees; sand boils and pipings; current standards for control methods are impractical (NCD)	a. Underseepage control methods compatible with observed performance; tolerable limits for seepage and sand boils; and better methods for estimating seepage
2. IMPROVEMENT OF FOUNDATION SOILS SUSCEPTIBLE TO LIQUEFACTION	
a. Sand foundations under existing embankments that are susceptible to liquefaction caused by earthquakes (SPD)	a. Remedial methods to eliminate liquefaction potential
b. Seismic stability (NPO)	b. Methods for establishing the liquefaction susceptibility of foundations under older dams to seismic loading
3. REMEDIAL CUTOFFS AND CONTROL METHODS FOR ADVERSE SEEPAGE IN EMBANKMENT-DAMS AND SOIL FOUNDATIONS	
a. Leakage in low-head flood control detention dams (NPD)	a. Low-cost water barriers to control leakage through embankments
b. Leakage through earth dams (MRD)	b. Expedient methods to control leakage at early stages
c. Underseepage at major dams; remedial treatment is expensive and dangerous (SAD)	c. Improved methods for remedial cutoffs; better cost-effective means of reducing seepage
d. Seepage under embankments into and through solution channels (ORD)	d. (1) Better relief wells including filters (2) Detection methods for seepage
e. Seepage under dams (NPD)	e. Technical/economic evaluation of methods for cutoffs versus seepage collection/control

(Continued)

Table BIII-1 (Continued)

Problem	User Needs
Evaluation of Soil Conditions and/or Performance	
1. ALLOWABLE MOVEMENTS AND PERFORMANCE CRITERIA	
a. Aging structures (NAD)	a. (1) Allowable movements for old lock and dam structures (>60 years old)
	(2) Performance: evaluation of basis for criteria changes
b. Aging structures (NCD)	b. Condition evaluation methods for structures >80 years old
c. Condition of older structures; do not meet current standards (ORD)	c. (1) Determine acceptable level of stability
	(2) Methods to evaluate interaction between structures and earth
	(3) Evaluation of differences between actual and theoretical condition
	(4) Economical methods of investigation and evaluation of condition
	(5) Methods of determining in-place properties of embankment materials for use in condition evaluations of older dams
d. Stability problems (NPD)	d. Methods to determine:
(1) Earth dams	(1) Allowable movements
(2) Structures on soil foundations	(2) Amount of movement without stability problem
e. Surface cracks in embankments (NED)	e. (1) Evaluation of causes
	(2) Repair methods
f. Movement of structures (NPD)	f. Capability for accurately measuring the movement of structures
g. Technology transfer (ORD)	g. Case histories: evaluate District experience with successful repair and publish guide to recommended practices

(Continued)

Table BIII-1 (Continued)

Problem	User Needs
Maintenance of Soil Features	
1. RESTORATION OF DRAINAGE SYSTEMS	
a. Deteriorating subdrains with clay pipe (NAD)	a. (1) Lower cost replacement materials; e.g., PVC pipe and filter cloth
	(2) Improved drainage systems
b. Ineffective drains due to water chemicals and root growth (NAD)	b. (1) Methods of restoring existing subdrain systems
	(2) Methods of maintaining existing subdrain systems
	(3) Methods of monitoring existing subdrain systems
c. Deterioration of channel subdrains (>40 years old) and side drains (SWD)	c. (1) Improved repair and replacement methods
	(2) Evaluation of effects of deferred maintenance
d. Cannot inspect filter and drainage zones in embankments (SPD)	d. (1) Methods to determine if filters and drains are operating properly
	(2) Methods to evaluate filter/drain cementation and effects on self-healing properties
2. RESTORATION OF RELIEF WELLS	
a. Deterioration of steel pipe piezometers (MRD)	a. Less costly, more durable replacement materials
b. Deterioration of wood stave relief wells (MRD)	b. Replacement alternatives
c. Relief well installations using mud (SWD)	c. Well development methods to remove deleterious materials; e.g., "revert"
d. Seepage under embankments (ORD)	d. Better relief wells, including filters

(Continued)

Table BIII-1 (Continued)

Problem	User Needs
Maintenance of Soil Features (Continued)	
3. METHODS FOR MAINTAINING WELLS AND SEEPAGE CONTROL IN COLD REGIONS	
a. Relief well malfunctions in cold regions (CRREL)	a. Methods for maintaining functioning wells in cold regions
4. GEOTECHNICAL APPLICATIONS FOR SOIL EROSION CONTROL AND SLOPE STABILIZATION	
a. Benching of upstream riprap protection (NCD)	a. (1) Less costly alternatives to rock slope protection
	(2) Slope stabilization
	(3) Repair methods
b. Seepage in slopes (NCD)	b. Seepage control and slope stabilization methods
c. Sloughing of banks (NCD)	c. Bank stabilization and/or protection methods
d. Shallow piping and caving of slopes constructed from dispersive and high-plasticity clays (SWD)	d. (1) Repair methods
	(2) Stabilization of materials in-place
e. Scouring beyond riprap (LMVD)	e. Preventive and repair methods
f. Active bank caving (LMVD)	f. (1) Bank stabilization and/or protection methods
	(2) Protection against effects of rapid drawdown and receding flows
g. Small failures of protected banks (LMVD)	g. Repair methods
h. Low probability use spillways (NPD)	h. (1) Methods to determine erodibility of spillways
	(2) Acceptable applications for unlined spillways

(Continued)

Table BIII-1 (Continued)

Problem	User Needs
Maintenance of Soil Features (Continued)	
4. GEOTECHNICAL APPLICATIONS FOR SOIL EROSION CONTROL AND SLOPE STABILIZATION (Continued)	
i. Erosive effects on wind and water (CERL)	i. Develop techniques for chemical dust palliatives to stem erosion and accelerate revegetation
j. Soil erosion in dispersive clays (MRD)	j. (1) Investigate fly ash and other lower cost alternatives to lime treatment
	(2) Investigate long-term stability of modified dispersive clays
k. Riprap repairs (MRD)	k. Alternatives to rock slope protection
l. Slope protection failures (NAD)	l. (1) Determine cause of side slope erosion failure of slope protection
	(2) Test alternative slope protection materials
	(3) Develop monitoring system for alternative methods of slope protection
m. Bank erosion in small navigation channels (SWD)	m. Economical control of erosion caused by wave action
n. Piping and subsidence (sinholes) from rainfall (not solution channel sinkholes) (SAD)	n. Determine cause and mechanisms and develop repair methods
o. Berm erosion on dikes (SAD)	o. Economical cost-effective methods to combat erosion
p. Erosion of channel bottoms (potential undermining of structures) (SAD)	p. Cost-effective erosion control methods
q. Erosion in high-velocity currents near waterfront docks/piers in rapidly fluctuating lakes and rivers (SAD)	q. Low-maintenance quick methods to resist extreme operating conditions

(Continued)

Table BIII-1 (Concluded)

Problem	User Needs
Maintenance of Soil Features (Continued)	
4. GEOTECHNICAL APPLICATIONS FOR SOIL EROSION CONTROL AND SLOPE STABILIZATION (Continued)	
r. Overuse damage (compaction of soil, erosion, etc.) (SAD)	r. Erosion control methods
s. Streambank erosion (ORD)	s. Materials and methods other than riprap to prevent erosion
t. Erosion in river banks (SPD)	t. (1) Better understanding of erosion problems (2) Better stabilization/erosion control methods
u. High-velocity channel repairs (LMVD)	u. Develop techniques for placing filter cloth in high-velocity locations
v. Sloughing of reservoir embankments under partial pool and on first filling (NED)	v. Slope stabilization and evaluation for maximum events
5. EROSION CONTROL IN COLD REGIONS	
a. Ice damage to riprap on embankments (SWD)	a. Alternative methods for slope protection (larger rock is not a solution)
b. Winter conditions (CRREL)	b. Protection against seasonal freezing and thawing effects

and appurtenant structures are the source of frequent problems; of particular importance are underseepage, such as occurs in alluvial soil foundations or in solution channels, and instability, such as potential for liquefaction during seismic activity. Slopes as well as channels are also problem areas involving seepage and erosion which lead to instability. Auxiliary features such as roads require regular maintenance and repair.

The more serious problems, such as potential liquefaction of foundations for major dams, are related to extreme events such as storms and earthquakes. Repair and maintenance problems are related to sustained life-cycle operations such as loss of efficiency in seepage control systems. Changes which increase the levels of flood protection result in higher hydraulic heads and greater seepage problems. Lesser problems are usually related to long-term deterioration of aging facilities and maintenance deficiencies.

Whenever soils are disturbed or subjected to changes in conditions (sometimes by only slight changes in stress or load applications) the potential for problems arises. Many of the problems can be equated to limitations of knowledge at the time of design and construction; for example, older embankments constructed using earth-rock mixtures were designed based on test methods and compaction procedures which are now known to be inadequate. Other problems (e.g., recent recognition of the need for better evaluation of liquefaction susceptibility) are recognized as a consequence of technological advancement. Still others are the result of testing by events of unprecedented magnitude; for example, levees on the Upper Mississippi River have recently been tested by record floods and exhibited adverse seepage conditions which could not have been foreseen when initially designed. Some problems reflect false economy measures or deferred maintenance that causes deterioration to continue, if not accelerate. Some problems are related to the use of Terzaghi's observational approach to avoid unnecessary conservatism; e.g., the use of a limited number of relief wells initially and addition of more wells only when field performance indicates they are needed. This approach is also used to circumvent the limitations in knowledge

at the time of design. Some problems arise and worsen sequentially; e.g., the overtopping of embankments and subsequent failure may be caused by massive slope failures inducing an overtopping wave, or may be the result of insufficient spillway capacity, or may be caused by an earthquake which triggers a slope failure or damages (blocks) an outlet works. Each of these is a serious problem; collectively, they may result in a disaster.

Soil problems are often related to minor geological details that are difficult, if not impossible, to detect. Such features may have been overlooked in site investigation, design, or construction and subsequently caused maintenance problems; problems caused by some of these oversights may even dictate remedial measures.

Problems may occur suddenly, without warning, and as a result of extreme events; e.g., earthquakes. Other problems develop slowly with wear and tear until limits of tolerance have been exceeded; e.g., deteriorating pipe drains, relief well screens, and exposed timber pile foundations. Some problems are management related, aggravated or compounded by deferred maintenance due to inadequate resources.

The cause of problems may be related to climatic conditions, changes in the water regime, activities of man, or improper use of materials; newly developed products are particularly prone to overuse without proper constraints and for purposes for which they were never intended. Problems may be related to the frequency and duration for an event; e.g., earthquakes and floods. They may be recurring by nature; e.g., clogging drains, deteriorating road surfaces, icing, and equipment failures require regular maintenance, periodic restoration, and sometimes periodic replacement.

Specific Adverse Effects of Problems

Almost without exception the problems identified by the Division offices are now or will be adversely affecting project operations and the public; even the functional mission of some projects may be in jeopardy. Some of the problems reflect deficiencies in planning, engineering, and construction, but the consequences of failure to address the problems impact the projects, the Corps, and ultimately

the public. Costs of rehabilitating a project may be very high in absolute terms, but may be small relative to the alternative; e.g., decommissioning the project, which would undoubtedly exceed the total cost of the project plus projected benefit losses. Projected costs of remedial measures for embankment modifications for seepage and stability deficiencies, under-seepage cutoff improvements, foundation stabilization, improvement of seepage collection systems, abutment seepage control, and embankment slides, required in recent years and continuing today (FY 1979-1983) as a result of the dam safety assurance program, are in the millions of dollars. Problems requiring only evaluation of conditions or performance must be considered relative to the costs of major elements at risk. Preventive measures may be quite expensive but easily deferred if not required immediately; however, timely maintenance can avoid overly expensive, even unnecessary, rehabilitation costs. Maintenance costs millions of dollars annually, but if not properly done may lead to rehabilitation or, at the least, higher maintenance costs. The specific costs of a problem are project-related (i.e., size, scope, etc.) and cannot be easily generalized.

Previous Problem Recognition and Treatment

Previously, REMR-related problems needing research relied on the Civil Works R&D (General Investigations) Program for resources; this approach has been neither timely nor adequate. Numerous REMR soil problems identified previously were rated with respect to Corps needs in order of priority for research. Local and regional problems and problems specifically related to maintenance often ranked lower in priority than safety related needs associated with design and construction of new projects, particularly problems associated with larger projects involving unprecedented engineering challenges. Since the identified research needs far exceeded the R&D resources available to address them, most problems of low priority (however meritorious) have not been studied. Given this emphasis, the "high-priority" problems have generally been of Corps-wide interest.

The mission problems considered in developing the proposed FY 1983 Civil Works R&D (General Investigations) Soil Program that are related

to REMR are listed in Table BIII-2. The current status of related research is shown, and the relevance to REMR is identified. REMR problems may benefit directly or indirectly from current, recently completed, or past research. Initially, an effective technology transfer program could provide some immediate benefits from R&D which has been largely oriented toward design and construction. In preparing the FY 1982-1983 Civil Works R&D (General Investigations) Soils Program, potential REMR applications and needs were partially considered in developing the objectives, technical approaches, and user products for the research work units which were based on the priority of mission problems. However, research on many of these problems is inactive or unfunded; thus, REMR needs will not be addressed to any significant degree. Relevant FY 1982-1983 work units under the Civil Works R&D Materials-Soils Program are listed in Table BIII-3; some of the REMR applications are identified where appropriate.

Technical reports on research results, technical guidelines, and user products produced in recent years would be beneficial to treating some of the REMR problems identified in Table BIII-1. They do not completely satisfy the identified needs, but may be useful to varying degrees.

The U. S. Bureau of Reclamation (BR) initiated a biennial Review of Maintenance Program in 1948 and an Examination of Existing Structures Program in 1965. A current program, Safety Evaluation of Existing Dams (SEED), resolves a need for intensive reviews. The BR's SEED Program involves some of the same aspects as the REMR Program, though the emphasis is different. However, since many of the problems have common causative factors and mechanisms, the REMR Program could benefit from an early examination of the SEED Program.

Problem Assessment

Nature of the Problems

The most severe problems arise when evaluations of existing projects reveal deficiencies which potentially could result in failure if not

Table BIII-2

Mission Problems* Related to REMR Considered

In Developing the FY 1983 Soils Program

Mission Problem Number	Title	Research Status 1 July 1982	Relevance to REMR Soils Problems
11-004-8	Cyclic Triaxial Tests	Complete FY 83	Indirect: seismic stability
11-006-8	Measurement of In Situ Static Properties	Inactive	Indirect: condition evaluations
11-008-8	Development of a Technique and/or Device to Evaluate the Liquefaction Potential of In Situ Cohesionless Material	Complete FY 83	Direct: liquefaction potential
11-009-8	Strength and Deformation Properties of Clay Shales	Complete FY 83	Indirect: slope and foundation instability
11-010-8	Strength and Deformation Properties of Earth-Rock Mixtures	Complete FY 82	Indirect: evaluation of older embankments
11-011-8	Design of Filters for Earth and Rockfill Dams	Complete FY 84	Indirect: aging drainage systems
11-018-0	Analysis of Zoned Earth and Rockfill Dams	Complete FY 84	Indirect: cracking; condition evaluations
11-020-8	Earthquake Resistance of Earth and Rockfill Dams	Unfunded	Indirect: seismic stability
11-025-9	Performance of Rockfill Embankments under Critical Flow Conditions	FY 81-86	Direct: overtopping
11-032-9	Remedial Measures for Foundations on Potential Liquefiable Soils	Unfunded	Direct: remedial liquefaction prevention
11-035-9	Cracking of Embankments	Complete FY 84	Indirect: cracking; condition evaluations
11-038-9	Influence of Aging on Performance of Embankment Dams	Unfunded	Direct: aging/deteriorating embankments, foundations, drainage systems
11-053-9	Determination of In Situ Densities of Granular Soils	Unfunded	Direct: remedial liquefaction prevention

* Based on December 1981 Civil Works R&D, General Investigations, projects.

Table BIII-2 (Continued)

Mission Problem Number	Title	Research Status 1 July 1982	Relevance to REMR Soils Problems
11-062-0	Observational Approach of Permanent Displacements in Embankment Dams Predicted by Newmark-Ambraseys Analysis	Unfunded	Indirect: seismic stability
11-065-0	Response to Earth and Rockfill Dams to Earthquakes	Inactive	Indirect: seismic stability
11-066-0	Applicability of In Situ Strength to Stability Analysis	Unfunded	Direct: allowable movements/performance criteria
11-069-1	Evaluation of and Design for Critical Conditions Due to Underseepage of the Landside Toe of Levees or Berms	Unfunded	Direct: remedial underseepage control
11-070-1	Prediction of Expected Bank Erosion in Inland Shallow-Draft Waterways	Unfunded	Indirect: erosion control
11-071-1	Probabilistic Techniques in Geotechnical Design	FY 81-86	Indirect: performance criteria/condition evaluations
11-072-1	Dissipation of Construction Pore Water Pressures in Clay	Complete FY 83	Indirect: foundation evaluations
11-073-1	Prediction or Extrapolation Dynamic Soil Parameters	Unfunded	Indirect: seismic stability
11-074-1	Design of Rockfill Dams and Cofferdams for Overtopping	FY 81-86	Direct: overtopping
11-075-1	Evaluation of Effectiveness of In Situ Densification	Unfunded	Direct: remedial liquefaction prevention
11-076-1	Seismically Induced Settlements	Unfunded	Indirect: seismic stability
11-077-1	In Situ Void Ratio Determination in Gravelly Soils	Unfunded	Direct: remedial liquefaction prevention
11-078-1	Effects of Soil Saturation on Liquefaction Potential	Unfunded	Direct: remedial liquefaction prevention
12-016-1	Risk-Based Analyses (Probability of Failure)	FY 81-86	Indirect: condition evaluations/performance criteria

(Continued)

Table BIII-2 (Continued)

Mission Problem Number	Title	Research Status 1 July 1982	Relevance to REMR Soils Problems
13-037-9	Rehabilitation of Older Civil Works Structures	Unfunded	Direct: remedial liquefaction prevention/remedial seepage control/ pile-supported structures Indirect: condition evaluations
14-004-8	Soil-Structure Interaction Studies	Unfunded	Indirect: condition evaluations/ remedial evaluations
14-012-0	Drag Forces Acting on a Structure	Unfunded	Indirect: condition evaluations/ remedial evaluations
14-014-0	Criteria for Use of Plastic Pipe in Civil Works	Unfunded	Direct: replacement of aging drainage systems
24-013-0	Case Histories of Coastal Projects	Unfunded	Direct: stability/ settlement evaluation of Charleston/ Georgetown Harbor Jetties
31-007-9	Evaluation of Existing Bank Protection Methods	Unfunded	Indirect: erosion control
31-015-9	Effects of Changing Water Levels on Streambank Stability and Protection	Unfunded	Indirect: reservoir and bank instability damage to waterfront structures
31-024-0	Bank Protection Alternatives for Alluvial River Channels	Unfunded	Indirect: erosion control/ reservoir and bank instability
33-030-0	Dredged Material Dikes	Unfunded	Direct: dredged material disposal
33-037-1	Construction of Hydraulically Dredged Levees	Unfunded	Direct: dredged material disposal
33-045-1	Data Management System for Disposal of Dredged Material	Active reimbursable projects	Direct: dredge disposal management

(Continued)

Table BIII-2 (Concluded)

Mission Problem Number	Title	Research Status 1 July 1982	Relevance to REMR Soils Problems
41-025-0	Dust Control at Corps of Engineers Construction Sites	Unfunded	Indirect: erosion control
61-001-8	High-Precision Monitoring of Tilts in Concrete Structures	Unfunded	Direct: foundation performance evaluations/allowable movements/advanced instrumentation
61-002-8	Simple Monitoring Device for Use by Dam Personnel	Unfunded	Direct: advanced instrumentation
61-003-8	High-Precision Monitoring of Movements in Concrete Structures	Unfunded	Direct: foundation performance evaluations/advanced instrumentation/allowable movements

Table BIII-3

Recent Soils Program R&D* Applicable to REMR

R&D Focus	REMR Problem** Reference to Table BIII-1	
Properties of Earth-Rock Mixtures	E	1c(5)
Dynamic Properties of Well-Graded Soils	R	2a, b
Properties of Clay Shales	E	1c, d
	M	4d
Properties of Dispersive Clays	M	4d, j
In Situ Techniques for Determining		
Liquefaction Potential	R	2b
Cracking in Embankments	E	1e
Granular Filters	R	1a, 3d, e
	E	1d, e
	M	1, 2
Liquefaction During Earthquakes	R	2a, b
Streambank Erosion (Section 32 Program)	M	4, 5 (all aspects)

* Based on Mission Problems, dated December 1981, Civil Works R&D, General Investigations.

** R = Remedial Improvements.

E = Evaluation of Soil Conditions and/or Performance.

M = Maintenance of Soil Features.

corrected; when the consequences are great, remedial measures must be undertaken.

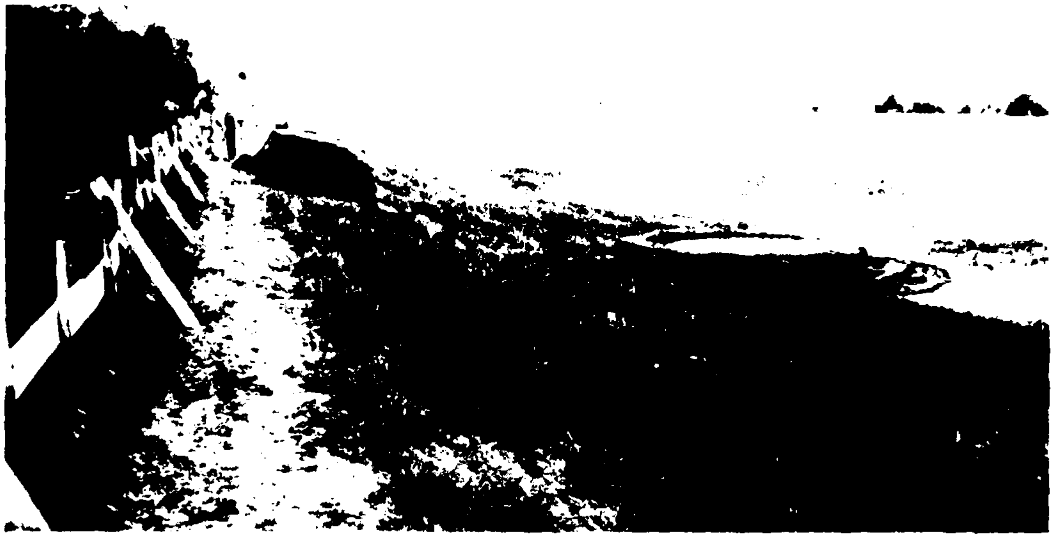
Remedial Problems

Major problems were identified that exceed normal project maintenance practices. These involve significant project deficiencies, malfunctions of critical components, or changes in functional requirements. The investigation of these problems involves specialized technical procedures; similarly, the remedies may be unique or experimental and often require some highly specialized capability for implementation. Special considerations are necessary to implement remedial measures, most of which involve major repairs or structural modifications to eliminate or control a serious or critical soil, structure, or foundation deficiency. For example, acceptable remedial measures have not been demonstrated for foundations determined to be susceptible to liquefaction during earthquakes, nor have the effects of various conceptual solutions on existing structures been evaluated. An example of the consequences of the lack of knowledge is shown in Figure BIII-1. Similarly, solutions for major underseepage problems need particular attention. Mainline levees (e.g., those of the upper Mississippi River and others on alluvial foundations) are being rehabilitated to meet modern hydraulic-hydrologic standards; current guidelines are seriously deficient in several aspects involving technical uncertainties which lead to excessive maintenance and repair costs. These adverse conditions are dramatically shown in Figure BIII-2. Seepage through embankment-dams and foundations is of great concern. Of lesser concern are foundation problems for pile-supported structures.

Condition and Performance Problems

Problems best addressed by an evaluation of present soil conditions or by an analysis of structure or foundation performance are less critical in that the specific problems may not require immediate attention. Even though proper treatment would be cost-effective, the resources may not be available; thus, the risk must be weighed and accepted when the loss is economic but not life threatening. In this category, we find significant problems which need evaluation to determine the true nature of the problem rather than relying on some superficial evidence which

Figure BIII-1. Foundation liquefaction failure



a. Ringing of sand boil

b. Uncontrolled sand boil

Figure BIII-2. Adverse underseepage conditions

could be misleading. One of the significant deficiencies in most of the problem areas is the lack of clear definition of the problem and its causative mechanisms. Investigations and analyses of these problems are prerequisite to developing rational and reliable solutions.

The problems identified by the Division offices were predominantly distress type. Major failures were not identified, but many problems reflect concern for *potentially serious problems*. The most important problem is the relationship between actual and predicted performance. Of lesser concern are aging problems in embankments and foundations; consequences of potential overtopping; installation of new facilities in existing levees; problems of stability and settlement for certain types of structures; and seismic stability evaluations.

Essential to planning effective and timely maintenance and to minimizing necessary remedial measures is the capability to evaluate current conditions and the integrity of embankments, foundations, and related ground features. The field problems in this group relate to two principal issues. First, present abilities of project components to meet current and future functional missions must be ascertained. These assessments are often insufficient when past and present performance is the only basis for predicting response to future events or when evaluated in light of current technology and criteria. The influence of aging, usually extremely difficult to assess, needs to be addressed. Second, project modifications, remedial measures, or new projections such as hydrologic or seismic events of unprecedented magnitude necessitate extensive monitoring and alternative systems for predicting performance with greater reliability. Such capability is a prerequisite to developing dependable maintenance or remedial measures.

Maintenance Problems

Maintenance problems are usually less dramatic but costly; they are easily ignored or deferred but must ultimately be faced. Recurring problems were identified that were encountered in normal operations and maintenance; some routine, some not so routine. The following are examples requiring attention: common, nuisance, periodic, and often costly problems involving decreasing efficiency of seepage control and

drainage systems; erosion problems are widespread. Of lesser immediate concern, but nevertheless worthy of attention, are aging of embankments and materials; instrumentation failures and data handling costs; instability of reservoir and bank slopes; road deterioration; and vandalism.

Significance of the Problems

Remedial Measures

When a project cannot be safely operated to fulfill its mission, major repair, rehabilitation, or modification is mandatory to restore its functional capability. The alternative may be failure or decommissioning; neither is usually viable.

Evaluations

It is often necessary to evaluate the soil conditions and structural performance to determine the significance of specific or potential problems and to determine the need for rehabilitation, or repair, or maintenance, or even to provide a sound basis for doing nothing when faced with some uncertainties. Frequently, some problems require only an evaluation in order to identify means to effect cost savings. Other problems need evaluations to provide guidance for new activities or unprecedented events. Such evaluations are highly significant, but action on the problems can be deferred so long as they are scheduled in a timely manner to achieve the benefits without incurring additional problems caused by such deferral.

Maintenance

Maintenance problems usually must be treated as they arise to prevent progressive deterioration causing more serious damages and consequences, e.g., seepage control must be effective; erosion must be arrested; instrumentation must be functional; unstable slopes must be repaired and stabilized; and roads must be repaired. If such features are not properly maintained, the consequences may be severe. Maintenance is a continuing expense and a manpower-intensive activity; thus, it is easily deferred/neglected in spite of the consequences. Maintenance problems may be highly significant, dictating better, more efficient methods for keeping

the facilities in optimum operating condition.

Relation to Other Problems

The problems identified by the Division offices are not unique to REMR concerns with respect to existing projects; only the site-specific applications and conditions set them apart from similar problems. In fact, many of REMR problem solutions will be developed based on research for other purposes. Particularly, maintenance problems will be examined first to see where current technology can be adapted. Information gathered in the Streambank Erosion Control Program (Section 32 Program) will provide the basis for developing erosion control methods that may be effective for treating erosion problems at existing water resource projects. Technology developed from Military R&D for airfields and from Federal and local highway experience will be adapted to road maintenance problems. In general, the technology for solving many maintenance problems is available; adaption to project conditions may impose some special constraints and requirements.

Evaluations and remedial measures require investigations at the forefront of the state of knowledge. The results from the Civil Works R&D (General Investigations) will be exploited. Many of the current (FY 1981-1982) and proposed (FY 1983-1984) work units in the Soils Program are either directly or indirectly applicable. Certainly, what is learned from the REMR Research Program will be reflected in engineering and construction guidelines in order to avoid the same problems on future projects.

Research and Development Needs

Broadly based research is needed to solve the identified REMR problems. Primarily, REMR research needs are problem-specific, needing applied research rather than extension of basic knowledge. Research needs to address causative factors and mechanisms which are obscure, but essential to a dependable solution to the problems. Many of the

problems are multidisciplinary and cannot be solved independently. The research will require an integrated approach for conceptual solutions, laboratory and field experimental models, project demonstrations, monitoring and validation, and ultimately the development of user products and implementation of an effective technology transfer program. Technology transfer is an important need emphasized by the Division offices for expedient dissemination of information and implementation of technological advancements in the form of practical guidelines. Upgrading project operations to state-of-the-art technology must be accomplished expediently, and can be done only with timely distribution of results of investigations. User needs were identified in Table BIII-1. The research products are described in Section C. The forms and processes of Technology Transfer are described in Section D.

PART IV: GEOTECHNICAL--ROCK SUBAREA

Problem Identification

The Rock subarea includes problems that relate to engineering geology, rock mechanics, geomorphology, hydrogeology, and geophysics. The specific REMR problems identified by Corps Division offices may be grouped under a few general problem areas. Although the specific problem details were somewhat different, the same general problems were usually noted by several Division offices.

The high-priority problems and the associated user needs identified by the Division offices are listed under each problem heading in Table BIV-1. Table BIV-2 lists the problem areas and the Division(s) identifying or known to experience the problems. These problems are discussed in the following paragraphs. Following problem identifications, the needs are assessed in general terms.

Problem Description

The general REMR problems with rock-related features of Civil Works projects fall primarily into the two broad categories of repair and evaluation. It is difficult to establish distinct boundaries to the REMR problem categories. For example, evaluation of alternative repair methods and materials may make future repairs simpler and more lasting and may reduce the need for frequent maintenance or postpone the need for major rehabilitation.

Specific repair or rehabilitation problems identified by the Division offices that need solutions include repair of leaky rock foundations and abutments, leaky grout curtains, repair practices for slope protection, maintenance and repair of rock spillway channels, and evaluation of sliding stability with respect to performance. Many of these problems require evaluation of past repair practices, for effectiveness and cost, such as the effectiveness of various forms of seepage cutoffs, evaluation of erosion control methods, etc.

Table BIV-1

REMR Rock Problems Identified by Division Offices

Problem	Specific Needs
1. Difficulties in Meeting Sliding Stability Criteria (NAD, ORD)	Some older historically stable structures do not meet current criteria for sliding stability. Reevaluate criteria on basis of past satisfactory performance of those older structures. Guidelines for performing such a study
2. Grout Effectiveness Evaluation and Grout Placement (NCD, MRD, SAD, ORD, SPD, NPD, LMVD, SWD)	Establish methods of evaluating grout effectiveness and locating grout in foundations. Determine improvements to rock strength and seepage characteristics. Improve methods for placing grout to achieve desired results. Methods to repair leaky grout curtains, solution channels
3. Erosion of Rock Slopes and Channels (LMVD, NPD, MRD, SWD, SPD)	Improve methods to predict and detect erosion of rock spillway and navigation channels and improve repair practices. Develop outlet channel design to inhibit scour and erosion. Evaluate alternate slope protection designs, including surface treatments and anchorage requirements
4. Rock Foundations (NPD)	Study changes in material properties of foundations of aging structures. More and better instrumentation in older structures. Better understanding of interaction between structure and bedrock foundation
5. Allowable Movements of Structures on Rock (NPD)	Determine the amount of movement (shear, rotation, settlement, etc.) that can be safely tolerated for various structures and conditions. Better, more reliable and accurate instrumentation and monitoring equipment. Better understanding of rock-structure interaction

(Continued)

Table BIV-1 (Concluded)

Problem	Specific Needs
6. Rock Reinforcement and Anchorage (MRD, ORD, NPD, SAD)	Develop better methods for installing rock anchors and bolts. Develop better methods for estimating the degree of improvement to be expected from installing various types of anchorage. Evaluate methods used in successful field installations. Corrosion-resistant tendons
7. Armor Stone Protection (SWD, POD, LMVD, NCD, NAD, MRD, NED, SPD)	Repair of damage to and maintenance of stone protection on slopes, stone breakwaters and jetties. Better placement methods for large stone used in breakwaters and jetties. Better equipment and methods for placing stone for best results in slope protection. Study causes of maintenance problems of jetty and dike systems. Guidelines for collecting and evaluating data on breakage of armor units. Specific recommendations for obtaining strong durable stone and for minimizing breakage
8. Seepage Detection (NAD, SAD, ORD, NPD, MRD)	Better methods to detect amount and location of seepage through rock abutments and foundations. Better methods to detect and trace sinkholes and repair. Evaluate costs and effectiveness of various types of seepage cutoffs and control measures. Problems have occurred at numerous projects, including Walter F. George Dam, Hartwell Dam, Clemson Diversion Dikes, and Wolf Creek Dam. More reliable, longer lasting instrumentation (piezometers, etc.)

Table BIV-2

Identification of REMR Rock Problems

REMR Problem/Need	Office Identifying/Experiencing Problem										
	NED	NAD	SAD	NCD	ORD	LMVD	MRD	SWD	NPD	SPD	POD
1. Difficulties in Meeting Sliding Stability Criteria		X			X						
2. Grout Effectiveness Evaluation and Grout Placement			X	X	X	X	X	X	X	X	
3. Erosion of Rock Cha[illegible]ls and Slopes						X	X	X	X	X	
4. Rock Foundations									X		
5. Allowable Movements of Structures on Rock									X		
6. Rock Reinforcement and Anch[illegible]age			X		X		X		X		
7. Armor Stone Performance	X	X		X		X	X	X		X	X
8. Seepage Detection		X	X		X				X		

Problem Locations

Each Division identified one or more REMR rock problems. However, specific references to problems with rock features are strongly localized within Divisions. Consequently, measures taken to correct problems will generally benefit all Divisions, but only specific areas or Districts within Divisions in some cases. The problems with grout placement and evaluation of its effectiveness, rock erosion, groundwater monitoring, and seepage control are general in geographic distribution. Problems with deterioration of rock slopes and foundations are more localized and depend on climate, age of structure, and other factors.

The evaluation and repair of rock bolt and anchor installations has application to protection of natural and cut slopes in rock and to repair of stilling basins and linings of flood control tunnels, so improvements would benefit the Division offices over a wide geographic area. Better understanding of the natural geological processes influencing spillway channel erosion is needed to develop cost-effective structural and nonstructural methods to minimize this problem. Foundation stability is generally a nationwide concern.

Problem Occurrence

There are many possible answers to why, how, when, and where problems occur with rock-related features of Civil Works projects. Problems may be caused by extreme events (floods, winds, etc.), or they may be the result of design deficiencies. Many older Corps structures were built without the benefit of knowledge of modern rock mechanics principles. The art of applied rock mechanics is little more than two decades old, so many problems recognized today were not considered when the older structures were built decades ago. Difficulties in meeting current sliding stability criteria and the need to reinforce and anchor structures to rock may be due to lack of knowledge, or to deterioration of the rock (or structure) with time, or due to upward revisions of safety standards.

Natural and placed rock materials may be altered physically and chemically by exposure to air and water. Deterioration of armor stone and riprap and erosion of spillway slopes and channels may be partly

attributable to weathering processes. Combinations of cyclic loading and deformations, excavations, and imposed loads may cause closed joints to open. Weathering can then penetrate these discontinuities, and erosion and degradation of rock quality may ensue. Seepage flows may then increase, where previously they were insignificant. Advances in the study of rock mass deformation along natural zones of weakness have resulted in the adoption of more stringent stability criteria to ensure safety, where formerly more reliance was placed on intact rock strengths.

In summary, problems with rock features of Civil Works projects may be caused by inadequate knowledge, deterioration of rock with the passage of time, the population's need for greater assurances of safety, and adoption of more stringent safety and performance criteria.

Specific Problems

The high-priority problems, as identified by the Division offices, are discussed below. In addition to these high-priority problems are several having lower priorities which are not discussed and for which research work units are not proposed. These low-priority problems are in the areas of underwater survey techniques, seismic hazard evaluation, and beach erosion.

Difficulties in meeting sliding stability criteria. A problem was exemplified by NAD at Federal Lock and Dam, Troy, N. Y., in which a 66-year-old structure is apparently quite stable but does not meet the existing criteria for sliding stability. Expensive post-tensioned anchors and reaction blocks were recommended to accommodate the criteria, but it is suspected that the criteria require examination. Uniform guidelines for the required levels of stability and the nature of interaction between structures and their foundations were called for by ORD. If the problem of better definition of sliding stability criteria is not solved, there will be a continuation of the real risk of overconservatism and consequent economic repercussions.

Grout effectiveness evaluation and grout placement. Eight Divisions specifically identified or implied the need for evaluating grout used for seepage control or foundation repair and improving ways of placing grout. Underseepage control was given high importance by NCD,

MRD, SAD, ORD, SPD, and NPD. A rational basis is needed for choosing among alternatives for seepage control because of the expense and hazards to stability of constructing cutoff walls under existing structures. ORD is concerned with controlling seepage through solution channels in foundations and with the detection of seepage where the use of piezometers is difficult or impossible. LMVD, MRD, SPD, and NPD specified problems with the control of seepage through cracks and deteriorated water stops in old concrete structures. SWD and NPD called for research into foundation stabilization or rehabilitation through the use of grout. The coupled problem areas of evaluating grout effectiveness and improving the placement of grout impact the water retention capacities of reservoirs and the downstream hydrologic conditions below dams. However, the stability of the structures themselves is the greatest factor impacted by seepage control to the degree that complete collapse and release of the reservoir can arise from uncontrolled seepage.

Erosion of rock channels and slopes. The problem of rock surfaces deteriorating through weathering or erosion by flowing water was specified by LMVD, NPD, MRD, SWD, and SPD. LMVD and NPD call for research into the prediction of the rate and extent of rock erosion to be expected and the ways rock in low-use spillway erodes so as to incorporate the final roughness into flow capacity calculations. Additionally, MRD stated concern with high rock slope deterioration processes and the need for economical and effective repair methods. SWD desires research into the erosion and deterioration of slopes and channel sides cut into fat clay shales so that stabilization can be accomplished. The problem of rock-cut channel erosion and deterioration impacts upon the continued capability of facilities to control design floods without risks to downstream populations or to the integrity of the structures.

Rock foundations. Specific problems with rock foundations were identified only by NPD, but other Divisions have experienced problems in this area. Changes in material properties affect stability of aging structures, as does differential deformation of layered rock foundation; e.g. John Day Lock and Dam. The need exists for better understanding of the interaction between the structure and the foundation rock. To

develop this relationship, techniques are needed to accurately determine mechanical properties of rock and to predict changes in rock properties in inaccessible locations; e.g., beneath dams or behind tunnel linings. Improvements in instrumentation would be beneficial to all aspects of the problem.

Allowable movements of structures on rock. NPD expressed concern over the tolerable limits of movement of structures built on rock and also the degree of differential movement within the rock foundation that structures can tolerate without losing integrity. Corollary to the problem of allowable movements is the desire by NPD, SPD, and LMVD to have developed low-cost but accurate instrumentation to monitor the movements of older structures. The impact of the problem of allowable movement tolerances lies in the evaluation of the continued usefulness of facilities and, further, in their rehabilitation before they fail completely.

Rock reinforcement and anchorage. NPD, ORD, MRD, and SAD noted a major problem area in the economical and rational use of rock bolts, various anchor types, and tendons to stabilize structures founded on rock. Spillway slabs, dam monoliths, and buildings require stabilization and rehabilitation. In addition, the long-term effectiveness of rock anchorage systems needs to be investigated and improved.

Armor stone performance. Eight Divisions (POD, SPD, LMVD, NCD, NED, MRD, NAD, and SWD) stated major repair or rehabilitation requirements for armor stone and riprap. The problems encountered comprise large stone dislodgement, gradation, placement control, weathering breakdown, and overall protective structure stability. The impact of the problem of rehabilitation of stone protective structures is added expense for structure replacement, increased beach and shoreline erosion, loss of nearshore property, and potential loss of life during major meteorological events.

Seepage detection. Four Divisions specified a need for improved methods for detecting seepage through rock foundations and abutments. Leakage through major openings in rock abutments at Gathright Dam is one example. NAD suggested studying the application and effectiveness of

geophysical methods (e.g., SP and electrical resistivity) for detecting seepage zones through rock foundations and abutments. ORD requested investigation of problems connected with seepage through solution channels. Underseepage was cited by SAD as a serious problem at Walter F. George Dam, Clemson Diversion Dikes, and Hartwell Dam. NPD cited needs in control of seepage and suggested an evaluation of seepage cutoff alternatives. Additionally, evaluation of seepage flows is important in determining foundation stability and grouting requirements. These problems were addressed separately.

Problem Assessment

The complexity of rock masses and their susceptibility to sudden catastrophic failures present serious and challenging problems to the geotechnical engineer. Limitations of current geophysical tools, the selection of appropriate design parameters, and the limitations of present-day theory must often rely upon past experience for the solution to these problems. Experience gained from personal observation of failures, from preparing trial-and-error solutions, and from reviewing the experiences of others is often the only guideline available. While experience is a valuable teacher, in today's world of rapid inflation more cost-effective methods are required. As more Civil Works projects are built in close proximity to urban centers, the safety of the projects and, more importantly, the area's population have become the foremost concerns. To ensure that adequate consideration is given to safety throughout the life of a project, new, innovative evaluation and repair techniques are required. The problems associated with aging structures must be researched and technical guidance provided to the responsible Division offices promptly and in the most efficient manner (i.e., ETL's, EM's, Technical Reports, workshops).

The importance of the problems identified in earlier paragraphs is underscored by the fact that several Divisions often identify the same problem, thus indicating the degree of concern. Many of these problems are clearly interrelated, as discussed previously. For example,

degradation of the founding rock mass (foundations or slopes), whether caused by erosion, seepage, or other forces, affects the determination of whether or not a structure meets the sliding stability criteria and dictates the need for rock reinforcement. Also indicated is the fact that as structures age, the problem gets worse with time. In some instances, the estimated cost for repair may put the usefulness of the structure in doubt, leading to the design and construction of new structures. Thus, it becomes clear that research is required for the early detection of problems, methods to evaluate the seriousness of the problem, and once the problem has been evaluated, to determine the best way of effecting the repair of the rock foundation or slope.

PART V: HYDRAULICS

General Problem Description

This problem area addressed REMR activities related to various hydraulic structures. It is divided into two subareas: Flood Control and Navigation. This subdivision conforms to the current research and technology transfer framework. The Hydraulics problem area includes all hydraulic REMR problems not addressed by the Coastal problem area discussed in PART VI of this section.

Information compiled from Corps Divisions and District offices was used to determine the nature of the research needs associated with the Hydraulics problem area. The hydraulics problems are briefly discussed under the subarea headings of Flood Control and Navigation.

Flood Control

Large numbers of hydraulic structures designed and constructed by the Corps of Engineers and others since the early 1900's have experienced excessive scour in both the upstream and downstream approaches. These structures include emergency spillways, locks and dams, stilling basins, grade control structures, drainage structures, and bridge piers. Scour at high-level emergency spillways and downstream from stilling basins are two high-priority problems related to REMR of flood control structures. Operational problems caused by unusual approach flow conditions or floating debris are also important. Each of these problems is briefly discussed in subsequent paragraphs.

High-Level Emergency Spillway Scour

Numerous high-level emergency spillways without energy dissipators downstream are experiencing severe scour as they address flow frequencies ranging from only 10- to 50-year events. During recent years, Fort Worth District projects have experienced severe scour in the exit channels immediately downstream of the emergency spillways at Lewisville and Grapevine Dams. The flows experienced were less than 10 percent of the

design discharges but produced scour with depths up to 30 ft, widths up to several hundred feet, and lengths extending several thousand feet downstream. Emergency repairs and rehabilitation are essential to prevent further scour and undermining of the spillways. Numerous high-level emergency spillways in SWD and MRD are being evaluated to determine their potential for similar scour and feasible solutions. Many are having to be enlarged to convey larger design discharges (up to twice the original estimate) based on recent hydrologic events experienced and estimates of future maximum probable floods. The cost of such repair and rehabilitation varies from about $1-20 million for each project.

Scour Downstream from Stilling Basins

Numerous (about 50) navigation dams on the Ohio, Allegheny, Monongahela, and Mississippi Rivers have experienced excessive scour downstream from the stilling basins. Most of these structures were constructed several decades ago and will be required to operate for several more decades. Without adequate repair or rehabilitation of the area downstream from these structures, they could be undermined. Design criteria for protection of these areas is generally inadequate. For example, riprap protection was placed downstream from Montgomery Dam on the Ohio River in 1978 to protect the stilling basin from undermining. A survey of the riprap in 1981 indicated that much of this material had scoured. About $2-3 million is required to provide riprap protection downstream of each structure. Extensive maintenance is often required to rehabilitate or repair scour holes upstream and downstream from other types of hydraulic structures, especially after major runoff events. The Old River Low-Sill Control Structure has experienced over 100 ft of vertical scour downstream, endangering the stability of that important diversion structure. In order to assist in restricting the Mississippi River to its present course, a multimillion dollar auxiliary structure is under construction. Also, major repairs required to the existing low-sill structure after the 1973 flood amounted to about $40 million. Repair of a small structure that controls Lake St. Francis, Ark., required about $750,000.

Approach Flow Conditions to Spillways

Spillways with unique and unsymmetrical approach topography and structural geometry experience adverse flow conditions. Numerous physical model studies of original designs for major spillways have documented many of the unacceptable flow conditions. For example, lateral approach flow around spur dikes initially proposed for Hugo Dam caused 17-ft-high periodic surging of flow at the abutments. Flow around retaining walls and abutments (West Point Dam), along embankments (Cowanesque and Burlington Dams), through gates (Harry S. Truman Dam), and around piers and through stilling basins (Barkley Dam) has caused excessive concentration of flow, unstable flow conditions, periodic surging of flow on gates that induce vibration and upward displacement of control gates. Also, this can cause structural damage and severe scour (Old River Low-Sill Control Structure) and adverse flow and scour in natural ravines and emergency outlet channels (Los Esteros and Bloomington Dams). There are many more Corps spillways that have not been modeled such as the emergency spillway for Grapevine Dam that has experienced excessive scour downstream. In addition, there are many non-Corps spillways that need to be evaluated accurately with regard to spillway adequacy and dam safety interests. It is difficult to identify a priori and/or quantify all spillway approach flow problems because of the complex hydrodynamic interaction between the fluid and solid boundaries. It is equally difficult to develop the "most" cost-effective solution with only a numerical or physical model because both time and cost limit the number of alternatvies that may be investigated. As a result, the solution (although effective) may not necessarily be the best either hydrodynamically or with respect to cost. Physical hydraulic models have been and can continue to be successfully used to define approach flow conditions associated with and develop satisfactory structural and operational designs for numerous spillways and outlet works. However, with the availability of computers and software to conduct numerical approximations and techniques for solving theoretical hydrodynamic equations, it is desirable to select, test, evaluate, and improve existing candidate numerical models to develop a more cost-effective hybrid modeling capability.

Such an approach involves both numerical and physical models and would permit identification and quantification of many alternatives and reduce the number of physical model(s) and/or test(s). This result will assist in providing more cost-effective design and operation of spillways.

Floating Debris Control Systems

Floating debris including ice is an ongoing maintenance and safety problem in many reservoirs, lakes, waterways, and flood control channels. Recently completed sections of the Tenn-Tom Waterway (Columbus and Aliceville Spillway) have experienced large accumulations of debris which is expensive to remove and difficult to flush through a series of reservoirs and locks and dams. Older structures often experience debris damage to trash racks and gates and interference to navigation, hydropower, and flood control operations. Ice and debris jams against bridge piers and hydraulic structures often cause excessive scour, reduce or stop navigation and hydropower generation, and increase water surface elevations during critical flood control operations.

Navigation

The Corps experiences recurring problems with some navigation channels and structures. The high-priority REMR problems are discussed briefly in subsequent paragraphs.

Channel Reaches with High Accident Rates

Inland navigation channels are typically developed in natural alluvial streams and tend to follow the natural alignment to the extent possible. Many channels of older projects are well developed. This development has not always been coordinated, and in some cases problems have arisen in maintaining the channel or in controllability of vessels navigating the waterways. A recent study has shown that accidents on the inland waterways were clustered in particular reaches. In the study, thirty-five 10-mile reaches were identified with 10 or more accidents in a 5-year period, accounting for over 30 percent of the total accidents. Of these accidents, 67 percent involved bridges and/or locks and

69 percent involved bends within 1/2 mile of a structure, with 65 percent involving both. A high percentage of cases cited involved currents, alignment, channel size, bank suction, and shallow depths that caused unusually difficult navigation conditions. Accidents at bridges result in loss of life and costs exceeding $6 million annually. Accidents at locks are even more costly and can result in lost navigation depths resulting in closure of the waterway. With increases in hazardous material movements on waterways and potential threats to the environment and municipal water supplies, reduction of accidents or potential for accidents is very important.

Lock Gate Impact Barriers

Damage to miter gates by tows entering and exiting locks is a common occurrence. Repair of this damage normally requires several days to several months. The loss of the navigation system during repairs results in extensive monetary losses to shipping interests. For example, the relatively recent loss of a miter gate at Bankhead Lock on the Black Warrior River resulted in Corps repair costs of $3 million and the lock was out of operation for 173 days. The exact number of tows and cargos delayed and the time and cost required for repair of damaged lock gates throughout the inland water system are not known; however, two crews working year-round are required for repair of miter gates damaged on the Ohio River Waterway. In addition, damage has resulted from flooding associated with the loss of lock gates.

Scour Around Navigation Training Structures

Estuarine navigation training structures required for channels, headland protection, small boat harbor shelters, bridge piers, dock and harbor piers, and wharfs are all attacked by wave, wake, and current forces which scour and undermine the structures. These forces lessen the integrity of the structures, contributing to early failures. Early detection of scour at training structures would provide better information for reducing costly repair and increasing the effective structure life. Research is necessary to help identify means for early detection of scour problem areas and methods of cost-effective repair, including

possible structural protection from further scour-caused failures. The research would provide Districts and Divisions the needed information for them to make the most effective use of maintenance funds.

Damage to Training Structures

The repair of estuarine and riverine deep- and shallow-draft training structures has continued to be a significant maintenance cost within the Corps. In shallow-draft channels, this includes the repair of dikes and revetments which are damaged as a result of ice, impact from navigation, or undermining due to flow conditions. There is no guidance generally available to evaluate these damaged structures and to determine when rehabilitation or repair is more cost-effective than replacement of the structure. For example, in LMVD, the annual maintenance cost to repair dikes only in critical areas and place stone or articulated-concrete mattress revetment averages $20-25 million. The average age of dikes within LMVD is about 15 to 20 years, and these structures are designed to last essentially forever; therefore, it is anticipated that the maintenance costs will remain at the present level or increase slightly for the years to come. Research is needed to determine guidance for the repair or rehabilitation of estuarine and riverine deep- and shallow-draft training structures to provide the Districts and Divisions with information on the effective use of maintenance funds available.

PART VI: COASTAL

Background

REMR problems in the Coastal problem area have been divided into three tasks:

- a. Task A: Coastal Structures.
- b. Task B: Harbor Entrances and Coastal Channels.
- c. Task C: Shore Protection and Restoration.

These tasks are arranged in order of priority from A to C.

Breakwaters, jetties, revetments, seawalls, and bulkheads comprise the most common coastal structures constructed by the Corps of Engineers. REMR problems associated with these structures involve loss of or failure of the structure toe, excessive runup and overtopping, localized displacement of the cover layers, use of different types of armor overlays to rehabilitate deteriorating structures, and development and testing of new methods for evaluating damage to underwater portions of coastal structures. REMR of coastal structures is complicated by the necessity to work near to or from the structure or underwater in a sometimes hostile wave climate. Research is needed on the use of an overlayer in the repair of rubble-mound structures and in keying and transition problems encountered in reconstructing some structures. Simple structural modifications which will reduce excessive runup or overtopping and a means of measuring this reduction in the field are needed. Simple, efficient, and cost-effective means are needed to assess structural conditions.

Harbor entrances and coastal channels require research and development to more effectively execute the Corps' reponsibility for maintaining these channels. A technology improvement is necessary in the ability to quantify the complex wind-wave, tide, and wind-driven circulation effects on the hydrodynamic and sediment processes in coastal navigation channels in order to evaluate methods for reducing maintenance requirements for these channels. The ability to estimate the three-dimensional dynamics of water and sediments in the channels is basic to this problem. Numerical methods must be developed to accurately and reliably estimate the

three-dimensional dynamics for offshore channels in an efficient manner capable of being used cost-effectively and timely enough to solve real engineering problems faced by the field offices. Numerical methods developed must be capable of being applied to large-scale problems with long offshore channels in complex geometries. In addition, more quantitative methods must be developed for determining both the short-term and long-term fate of material from channel maintenance projects. The ability to more quantitatively evaluate the fate of dredged material is necessary for reducing maintenance dredging of these channels.

The Corps requires research and development to improve methods and techniques for evaluating shore protection and restoration projects. Improved techniques are required for rapid post-storm inspection and evaluation of nourishment projects, hurricane protection projects (dunes, coastal levees, hurricane barriers, etc.), and general storm-induced coastal erosion. Rapid and extremely accurate measurements of nearshore bathymetry and topography are necessary to quantify the true magnitude of erosion by storms.

Information developed from the Coastal problem area will contribute to the following EM's:

a. Coastal Project Monitoring.

b. Design of Breakwaters and Jetties.

c. Hydraulic Design of Coastal Groins.

d. Beach Erosion Control and Shore Protection Studies.

e. Hydraulic Design of Sand Bypassing Systems.

f. Design of Beachfills.

g. Regime Analysis of Inlets and Estuaries.

h. Hydraulic Design of Revetments, Seawalls, and Bulkheads.

Problem Description--Task A: Coastal Structures

Introduction

The problems and corresponding research needs described herein are directly related to REMR of existing coastal structures that are required to protect U. S. harbors, ports, marinas, and entrances to coastal

navigation channels. Such structures usually consist of breakwaters, jetties, seawalls, shoreline revetments, etc., and combinations thereof. Problems associated with these structures include:

a. Effective inspection and evaluation. Damage is usually limited to above water observations, and it is difficult to assess specific underwater damage.

b. Displacement of armor protection. Both substantive structural failure and displacement of individual units.

c. Localized damage that causes unraveling of armor protection. If spot damage is not effectively repaired, long-term deterioration is usually more difficult and more expensive to repair.

d. Structural damage to individual armor units. Excessive movement or breakage of armor can cause functional deterioration of the structure's overall stability and purpose.

e. Excessive wave runup and overtopping. Many existing structures were not designed for major runup and overtopping; thus, breaching of the crown, deterioration of the leeside slopes, and undesirable wave transmission add to repair and maintenance problems.

The Corps has direct responsibility for maintenance, repair, and rehabilitation of structures under its juridiction as well as permit responsibility for those structures developed by private enterprise. The need to reliably evaluate, understand, and implement repair and rehabilitation is paramount, since many existing structures have deteriorated (or are deteriorating) and either do not serve or only partially serve their original function. Due to curtailment of new construction, the service life of some existing structures is being extended. Several existing Corps structures are being rehabilitated to meet new and greater demands. Maintenance, repair, and rehabilitation are complicated by the fact that work must be performed from or near the structure under existing wave conditions and underwater retrieval and/or placement of armor protection is generally done by blind feel or touch. These problems and difficulties are directly reflected in the rapidly increasing O&M budgets (and those projected for future years) of the field offices. In the past, individual repair and rehabilitation project costs for coastal structures have ranged from about $1-10 million each and most structures have been rehabilitated more than one time. Appropriate

research in this area could potentially reduce repair and rehabilitation costs by at least 20 percent for each job and could very likely eliminate or substantially reduce the need for recurring repairs. Considering Corps-wide application of REMR research on coastal structures, long-term benefits are conservatively estimated to be many tens of millions of dollars. Long-term annual benefits of this research should be at least several million dollars.

Research is needed on how to:

a. Rehabilitate breakwater toes to preclude future maintenance requirements due to toe failure.

b. Effectively repair localized damage after the dollar magnitude and extent of this problem are thoroughly documented.

c. Use different types of armor overlays to rehabilitate deteriorating structures.

d. Evaluate damage to underwater portions of coastal structures.

e. Develop methods to rehabilitate coastal structures to reduce wave runup and overtopping after the dollar magnitude and extent of this problem are thoroughly documented.

Brief descriptions of specific problems and approaches to their solution follow.

Rehabilitation of Rubble-Mound Structure Toes

Numerous breakwater and jetty failures causing repair and/or rehabailitation are directly attributable to displacement or failure of the toe of the structure. Breakwater toes, especially those in relatively shallow water which is the case for almost, if not all, Corps coastal structures, are especially vulnerable to damage. Once damaged, the structure continues to gradually deteriorate with more and more of the armor protection being displaced near the toe. Eventually this damage will manifest itself in damage near and above sea level which is clearly visible. Figure BVI-1 shows an aerial photo of slumping and above water damage to a breakwater caused by instability of the toe. Breakwater toes are usually most vulnerable (in shallow water) at a low water level accompanied by large waves breaking over the toe area of the structure. No guidance exists for field offices on the proper method to effect

Figure BVI-1. Upslope damage due to toe instability

repairs and/or rehabilitation to breakwater toes. Research is urgently needed to provide this guidance. Substantial dollar savings can be realized if reliable guidance is developed for repairing the toe areas of coastal structures so they will not need continued periodic repair.

Reduction of Wave
Runup and Overtopping

As a result of excessive runup and overtopping, the crown areas of many existing breakwaters and jetties are being deteriorated (Figure BVI-2). This deterioration in turn allows breaching of the structure which results in lack of support for seaside armor, jeopardy of the lee-side armor, and poor functional performance. In other instances, undesirable runup and overtopping on seawalls, bulkheads, and revetments often exceed the original design event and cause seepage problems, loss of backfill material (Figure BVI-3), and general erosion of the protection-land interface (Figure BVI-4). These types of problems are especially prevalent on man-made islands, dredged material containment dikes, and land-based waterfront property. There is a definite need for research to quantify the dollar magnitude and extent of this problem on existing structures and whether it is of sufficient importance to provide the field with methods and techniques of repair and/or rehabilitation to reduce wave runup and overtopping.

Repair of Localized Damage

Due to the lack of guidance on repair of localized damage to coastal structures, most Districts and Divisions rely on experience and judgment to decide when and how to repair structures under their jurisdiction. There is an urgent need to disseminate the field experience, both successful and unsuccessful, throughout the Corps and to develop reliable guidance on the optimum method to use for such repairs. The extent and dollar magnitude of this problem will be quantified and additional research will provide guidance for effecting this kind of repair. Localized damage (Figure BVI-5) is almost always unique and special consideration has to be made to ensure an effective and lasting repair. This requirement means repair with like armor protection or the mixing or armor units (Figure BVI-6), but in either case, it is unlike new

Figure BVI-2. Crown deterioration

Figure BVI-3. Loss of backfill

Figure BVI-4. Erosion at the protection-land interface

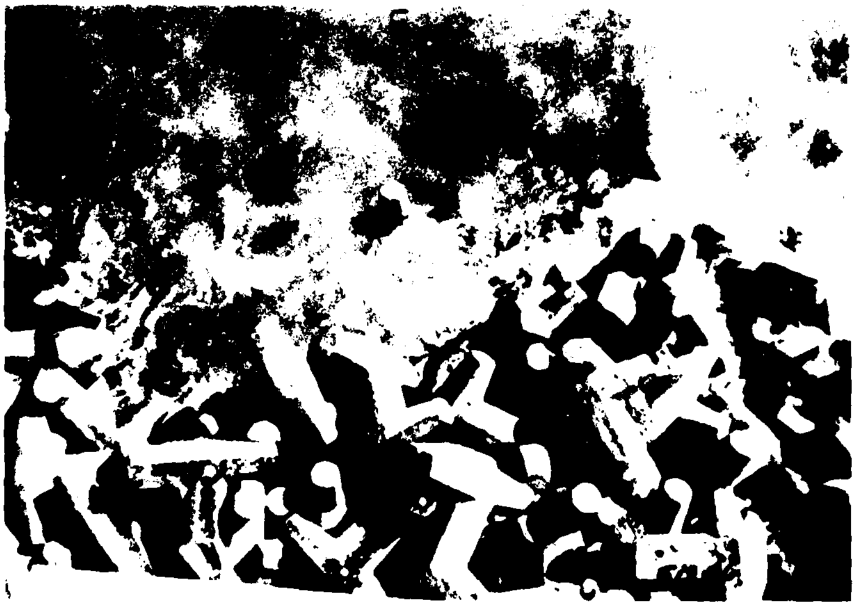


Figure BVI-5. Localized damage

Figure BVI-6. Mixing of armor units (tribar-dolos interface)

construction in that problems arise in getting new and/or different armor to effectively fit the interlocking matrix. Other questions arise concerning what types of armor mesh together best; what is the best technique for repair of onslope spot damage, end sections, toe areas, etc.; and does some of the existing armor have to be removed to implement effective repair? Answers to these questions can be developed through experimental research investigations and reporting of successful field experiences.

Use of Dissimilar Armor
for the Repair and Rehabilitation
of Rubble-Mound Coastal Structures

Many of the Corps' major breakwaters and jetties are being rehabilitated to extend their project life and/or to meet greater design demands. Design criteria for new structures require specific sizes of multilayered material and continuity in the placement of armor protection. A deteriorating structure (Figure BVI-7) may consist of a conglomerate of mixed material sizes; the old armor protection may be completely or

Figure BVI-7. Humboldt north jetty before rehabilitation

partly gone, making it difficult to level slopes; existing toe materials are usually deteriorated seaward requiring extended protection or expensive removal of existing materials to ensure adequate new toe stability; and often the head or crest of the structure is undermined or broken apart, making repair to the crown necessary before access to the real problem can begin. In the past, the solution to such problems has been selected based on engineering judgment or in more recent times on site-specific model studies. The engineering judgment process may be expensive since experience is very limited and there is not usually a solid basis for it. This process can lead to recurring failures that cost millions of dollars without a real solution being developed for the long-term problem. Site-specific model studies have provided satisfactory solutions (Figures BVI-8 and BVI-9), but again site-specific data usually fail to meet the requirements of other projects. For instance, field office use of various concrete units to overlay large stone (Figure BVI-10) and/or the overlaying of one layer of one type concrete armor unit over another (Figure BVI-11) may not be desirable and at most, is based on questionable

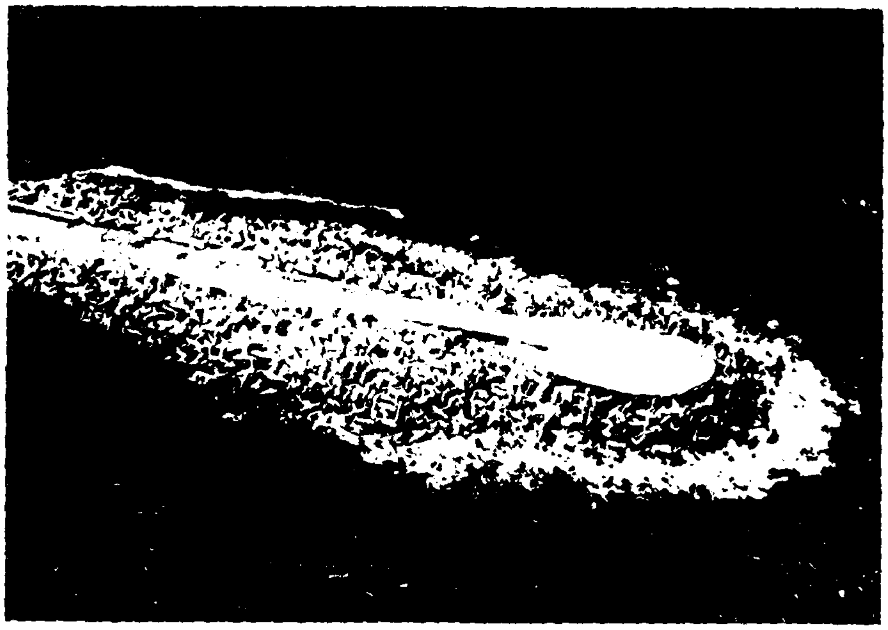


Figure BVI-8. Humboldt north jetty after rehabilitation

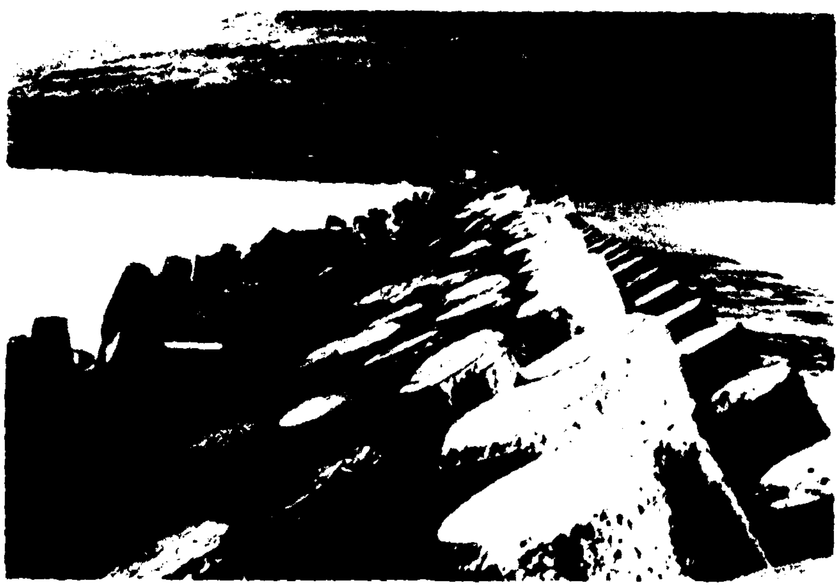


Figure BVI-9. Dolos overlaying tribars

Figure BVI-10. Tribars overlaying large stone

Figure BVI-11. One layer of dolos overlaying randomly placed tribars

quantitative information (for this type of repair) developed from new-structure design criteria. Field offices have need of and should be provided rehabilitation guidance on the use and interaction of overlay armor materials.

Coastal structures often suffer storm damage to underwater portions of the structure that cannot be detected by aerial photographs or visual inspections from the top of the structure. This damage is potentially extremely important since the next storm may cause the weakened structure to suffer major damage necessitating expensive and time-consuming repairs. This problem is prevalent for both stone and concrete armor unit structures. The field has rightfully taken advantage of the stability provided by interlocking of concrete armor units, but individual armor units on some projects have experienced excessive movement (Figure BVI-12) and/or breakage (Figure BVI-13). The performance of individual types of concrete armor units is now in question and no comprehensive effort is being made to determine the extent of damage different types of concrete armor are experiencing on the underwater portions of coastal structures. A requirement exists to develop methods for accurately delineating the extent of damage to underwater portions of coastal structures. If successful, as expected, the development of such a technique and the demonstration of its viability for operational use in the field would pay for itself many times over by detecting one situation of underwater damage which could be repaired before another major storm produced progressive and perhaps very major damage which would cost at least an order of magnitude more to repair.

Problem Description--Task B: Harbor Entrances and Coastal Channels

Introduction

Task B addresses a REMR problem and research requirement directly concerned with harbor entrances and coastal channels which is necessary for the United States to maintain modern and competitive harbors and

Figure BV1-12. Deterioration of tetrapods

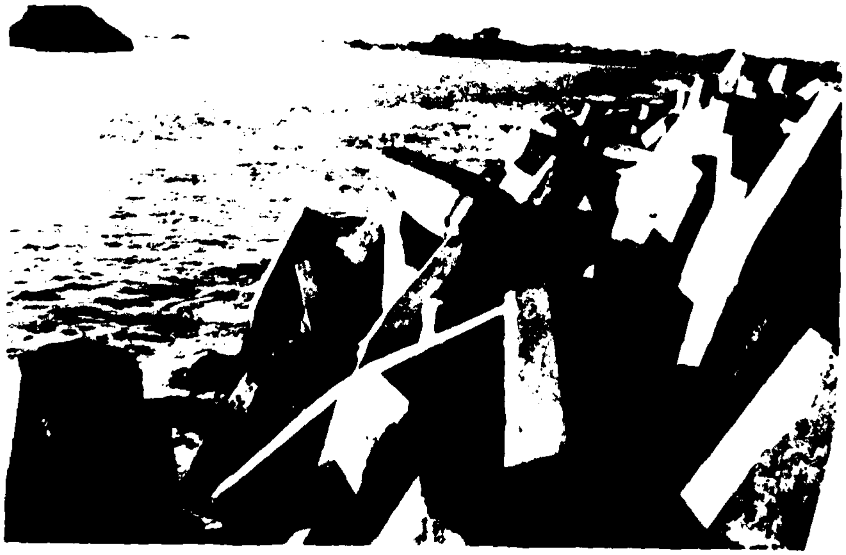


Figure BV1-13. Broken dolos

ports for the export and import of materials and goods on the international market. One major REMR problem is associated with this task.

The Corps of Engineers has the mission of maintaining U. S. navigation channels to their authorized depths. The research work unit in this task is urgently required to provide quantitative answers to questions concerning channel maintenance operations. The answer to these questions could lead to tremendous cost savings, improved environmental quality, and expanded recreational potential. Research is required to gain a comprehensive quantitative understanding of all phases of the movement of material requiring coastal navigation channels to need periodic and sometimes continuous maintenance. Commensurate with the navigation channel maintenance responsibility of the Corps is a responsibility to evaluate the effect of navigation projects on adjacent shorelines and to investigate methods for reducing maintenance requirements for offshore navigation channels.

Development of Advanced Methods and Techniques for Evaluating and Minimizing Maintenance Requirements of Coastal Navigation Channels

Costs for the Corps to maintain authorized depths of coastal navigation channels have increased dramatically in recent years. These increased costs are due to both increased costs of maintenance operations and increased costs associated with environmental constraints on material disposal. Figure BVI-14 shows a coastal navigation channel shoaled with sand near the ocean entrance and at the harbor entrance. Annual maintenance is required to maintain this channel to its authorized depths. In order to minimize maintenance costs, research is required to obtain the capability to make a comprehensive and reliable determination of the movement of bottom material within navigation channels and adjacent waters, the movement of maintenance material at disposal sites, and the response of various bottom sediments to hydrodynamic forces under varying chemical and environmental conditions, i.e., waves, tides, currents, etc. The technology is available to potentially make reliable estimates of the long-term behavior of this maintenance material for large-scale practical engineering applications. Recent theoretical and numerical advances have

Figure BVI-14. Channel shoaled with sand near ocean and harbor entrance

indicated a new three dimensional implicit/explicit numerical model approach to this problem coupled with comprehensive field data acquisition and use of state-of-the-art remote sensing devices can be expected to significantly improve our ability to quantitatively evaluate large-scale "real world" engineering problems of this type. This approach appears to be far superior in potential for application to Corps projects than numerical techniques currently in use. Additional research is required to develop this technology to a point where it can be reliably and efficiently applied to large-scale practical problems. Additional research also is needed to perform more detailed and large-scale calibration and verification of the accuracy and reliability of this novel numerical model approach to the problem. The development of such a tool will enable the Corps to quantitatively address both the engineering and environmental questions associated with the transport of maintenance material into navigation channels and the disposal of this maintenance material. It is conservatively estimated that this ability should produce enormous savings in disposal of uncontaminated (and possibly even contaminated) maintenance material.

Problem Description--Task C: Shore Protection and Restoration

Introduction

The Corps REMR-related responsibilities concerning shore protection and restoration are centered mostly in the evaluation portion of REMR. The Corps is responsible for nourishing authorized beaches, and this responsibility leads directly to the research effort required in this task. Improved techniques are required for post-storm evaluation of storm-induced erosion. More accurate and efficient equipment and techniques are required for measuring nearshore bathymetry. Research is necessary to provide the improvement required in evaluation techniques associated with shore protection and restoration. This research is discussed in more detail below.

Improved Techniques for Post-
Storm Inspection and Evaluation

Most substantive coastal erosion occurs during storms. However, the local beaches begin to recover and accrete sand very shortly after storm passage. Figure BVI-15 [illegible] an example of post-storm erosion. It is imperative that improved techniques be developed to measure nearshore bathymetry and topography (above and below mean sea level) rapidly and accurately for quantification of storm-induced erosion. Such measurements are needed for a reliable evaluation of erosion effects on dunes used for hurricane or storm protection, erosion of recreational beaches, erosion of beachfills, and storm-induced transport rates which maintenance systems must handle in short-term situations. Reliable evaluation of these erosion effects is basic to the rehabilitation and maintenance of dunes, determination of bypassing rates at navigation structures to maintain recreational beaches, and determination of critical fill ratios and the renourishment factor for beachfills. It is envisioned that the most desirable technique is some form of remote sensing which is of course practical for those areas above water; however, additional research is necessary to determine if remote sensing techniques can provide the necessary accuracy for bathymetric measurements and to determine the limiting depth that such measurements can be used as a function of environmental parameters. It is desirable to be able to measure the bathymetry to an accuracy of ± 1 cm in order to obtain an accurate estimate of changes in bathymetry seaward of the breaking zone in water depths from 6 to 10 meters. Such an accuracy is beyond the limit of current technology, and research is necessary to produce a system which can maintain such an accuracy and perform the measurements relatively rapidly. It is believed that the technology is available to develop such a capability.

Figure BVI-15. Typical beach erosion

PART VII: ELECTRICAL AND MECHANICAL

Problem Identification

Corrosion of metal structures results in billions of dollars of maintenance and repair each year in the United States. Water-based activities of the Corps of Engineers are, by their very nature, highly susceptible to this type of deterioration; therefore, corrosion mitigation is an important aspect of the Corps' maintenance programs. Failure to include this aspect in maintenance activities could necessitate very costly rehabilitation and replacement and could conceivably result in catastrophic failure with potential loss of life and property. Other similar areas of concern include maintenance and repair of rotating machinery, lock and tainter gates, and other hydraulic equipment, and energy conservation.

Fortunately, the Corps' corrosion mitigation and maintenance and repair activities have been highly successful over the years. However, they are becoming increasingly costly. In this age of scarce resources, it is necessary to improve the procedures whereby these activities are conducted while reducing costs. There are three methods for corrosion mitigation: cathodic protection, protective coatings, and proper material selection. Much has been accomplished in all of these areas, but considerable additional savings can be achieved through further research. Many corrosion problems originate from the design itself. Few designers have been schooled in the fundamentals of the corrosion phenomenon. With proper guidelines, designs that result in low-maintenance structures are readily attainable. Many smaller problems that result in high maintenance costs and undesirable downtime can be reduced or eliminated through research. These include items such as corrosion of wire rope in gate hoisting equipment, compatibility of different insulating oils and various grades of lubricating oils, maintainability of lock gate operating machinery, use of energy management and control systems, fire protection systems, and problems associated with birds roosting on Civil Works structures. Cavitation of turbine blades and the evaluation of the

electrical insulation of generator windings continue to be problems, and gate seals and gear and gate seal heaters do not always perform as designed. Research holds good promise for improving the performance of these items.

Problem Assessment

Although much has been done in the areas of corrosion mitigation, maintenance and repair, and evaluation of equipment, the problems have not been solved. Very little has been accomplished toward developing methods for nondestructive evaluation and service life prediction of structures and equipment, especially generator windings. More durable protection systems are required, as well as improved guidelines for proper material selection. Building with corrosion-resistant materials is one of the most effective ways of reducing corrosion problems. Guides for the designer that discuss metal selection and compatibility will provide the type of information that will result in more maintenance-free structures. New protective coatings that will meet air pollution regulations and yet accommodate the stringent requirements of Civil Works activities need to be developed. Many less visible but highly disruptive problems also need to be addressed. These include such things as: performance and durability of gate seals and heaters; the compatibility of various insulating oils and different grades of lubricating oils, as well as the use of synthetic oils to replace oils that require heating in cold weather to remain functional; development of energy management and control systems; substitute materials for the highly corrosion-susceptible wire rope used for hoisting tainter gates; improved maintainability of lock gate operating machinery; fire protection systems for Civil Works structures; and guidance for detering birds from roosting on Civil Works structures causing health, safety, and nuisance problems.

More specifically, the proposed research in this problem area will address: the development of procedures for nondestructive evaluation and remaining service life prediction of equipment and metal structures (especially rotating equipment); techniques for managing corrosion

mitigation activities; application of new technology and material selection guidelines to Civil Works structures; development of improved protective coatings and surface preparation techniques; and the series of miscellaneous problems detailed above.

The end product will be in the form of guide specifications, manuals, and technical reports.

PART VIII: ENVIRONMENTAL IMPACTS

Introduction

The environmental effects of REMR activities of the Corps of Engineers may appear, at first, to be relatively benign; however, due to the great diversity of alternative actions possible, the probability that significant adverse environmental impacts will occur must be considered. The environmental impacts for some REMR activities are expected to be temporary in nature and with proper measures these adverse impacts can be eliminated or environmental features may be enhanced. Conversely, permanent changes in project features that would change water quality or alter or replace habitat (e.g., use of rip-rap to control bank erosion or repair of structures in a manner that would permanently alter habitat type) will result in long-term impacts. Another category of REMR activity that may have long-term impacts is the rehabilitation of projects involving a change in purpose; e.g., addition of hydropower or a change in project operation. In this latter case, it will be necessary to address the broader environmental impacts associated with these REMR activities. From the standpoint of ameliorating any adverse environmental impacts, it is critical to identify the impacts due only to the REMR activity as precisely as possible. Adverse environmental impacts are possible with any REMR activity, but the severity and duration of these impacts are expected to vary widely and be extremely dependent on the precise nature of the REMR activity.

Potential adverse environmental impacts of REMR activities should be identified as early in the project as possible, preferably during the early planning phase. At this stage, when a wide range of REMR alternatives are available, impacts of each can be carefully evaluated to determine which alternative produces the minimum adverse impact while accomplishing the REMR objective. This consideration can not be overemphasized since delays in evaluating impacts may result in a project delay or costly modification or redesign to avoid significant, adverse impacts during the latter stages of the project. Additionally,

in the early stages of the project the addition of environmental features can be considered and easily added to the project to ameliorate adverse impacts. Alternate design or construction procedures (e.g., use of vegetation versus a structural alternative for erosion control) that specifically meet project objectives and may provide environmental enhancement should also be considered at this stage in conjunction with more conventional approaches.

An ultimate goal for R&D under the REMR program should be procedures to reduce the amount of repair or maintenance required at a specific project. This involves developing alternative design or construction techniques to meet this goal. These changes may dramatically effect the degree of environmental effects depending on the exact nature of the change proposed; consequently, it is very desirable to evaluate possible impacts early during the development of such procedures. Thus, close coordination between R&D on environmental impacts and other R&D within the program is necessary.

In assessing the success of REMR activities it is anticipated that pre- and post-construction monitoring will be required to evaluate specific activities. Similar requirements also apply to monitoring needed to assess the environmental impacts associated with a REMR activity. This information is also critical for determining the validity of evaluation procedures and for use in subsequent improvement of these techniques. Since monitoring activities are costly, it is also important to assess the usefulness of such procedures and required modification to ensure cost-effectiveness.

The scope of REMR is very large encompassing every category of Civil Works functions. Geographic distribution is wide encompassing ocean, coastal, estuarine, inland waterway, and reservoir environments. Given this wide diversity, specific environmental impacts and considerations are expected to vary proportionately. Under such conditions general procedures that are developed will have to be appropriately modified to reflect regional and site-specific considerations. The goal is to provide techniques with as wide an applicability as possible, but with the capability of being easily adapted to specific problems.

Specific Problem Areas

During the development of the needs for REMR R&D, many specific problem areas were identified in which environmental considerations are important. While an exhaustive treatment of all problem areas is not warranted, discussion of some examples would be beneficial to highlight some of the points raised previously.

Repair/maintenance/rehabilitation techniques

Environmental considerations associated with specific techniques must include evaluation of the construction or operational procedure to accomplish the objective. One alternative approach to reducing REMR requirements involves the use of nonstructural alternatives, specifically as they relate to flood control projects. This alternative has always been popular from an environmental standpoint, although attendant socioeconomic impacts may have some bearing on their selection and implementation. Since they generally preclude direct environmental impacts, these measures should be considered when appropriate. Dewatering of projects to accomplish repair and maintenance is a costly procedure, and a need to develop techniques that can be used underwater has been identified as critical. Dewatering also has environmental impacts particularly if stream flows are interrupted for a long time or if habitats are exposed to dessicating conditions. These changes can impact fisheries and sensitive species on affected habitats plus altering water quality. Underwater techniques which allow for normal project operations, would avoid these problems, but could conceivably affect water quality depending on materials used. In some cases it is necessary to remove sediment and debris from stilling basins for maintenance purposes. Proper disposal of removed material is required to minimize impacts of this operation. Evacuation of sediments by flushing, or in general, other techniques that increase sediment loads will impact water quality. Possible impacts include interruption of primary productivity and increased transport of nutrients or other contaminants associated with these sediments. Wastewater collection and treatment associated with recreation facilities are in need of replacement or modification at

many projects. The selection of techniques to accomplish this must meet required treatment standards as well as being able to handle widely varying loading conditions. It is generally very difficult to accomplish this without high operational costs. Restoration of construction sites, fill areas, special environments (e.g., arid, wetlands, cold regions), or problem soils is a specific concern when developing techniques to reduce adverse impacts of REMR activities.

Repair and maintenance materials

The types of materials used in the repair and maintenance of projects include a wide variety of grouts, paints, sealants, and patching materials for many purposes. Depending on the application techniques and circumstances these materials will be subjected to a diversity of environmental conditions with results that are not easily predictable. For those areas where application may be underwater, the possibility of adverse impacts on water quality must be considered. Little information exists on the leachability and durability of these materials; consequently, an adequate assessment of water impacts can not be made. In some instances the use of a material, such as herbicides for vegetation control, or production of an oil discharge from a REMR activity has a documented impact. For these areas procedures that minimize the water quality impact or suitable alternatives must be developed.

Design alternatives

As mentioned previously, design alternatives that reduce the requirement for REMR activities are very desirable. There are a variety of examples in this category ranging from channel design (including depth, alignment, velocity) to debris basins, jetties, and breakwaters that have been identified as critical project categories. Design changes may also reduce existing adverse impacts and may, in an ancillary fashion, incorporate additional purposes (e.g., fish and wildlife, recreation) to the project. It is essential that the impacts of design changes be carefully evaluated and considered when weighing the benefits and costs of adopting any design changes. The use of alternative design, such as vegetation for erosion control as opposed to more conventional approaches, offers the potential of environmental

enhancement to the project. Alternative designs which incorporate environmental features should be considered whenever possible.

Evaluation procedures

The development of cost-effective and reliable evaluation procedures for determining the environmental effects of REMR activities is critical to addressing environmental and water quality considerations. Procedures are required for determining impacts of rehabilitation procedures; for example, addition of hydropower, selective withdrawal, and many other design or operational scenarios. These procedures may range from simplified regression techniques for water quality impacts to complex models to determine the impacts on fishery resources. The precise needs are difficult to determine in advance, but available techniques should be of such diversity and capability to address a wide range of situations. Other examples are a carrying capacity model to predict allowable visitation at recreation facilities to avoid increased maintenance or repair costs and models to predict impacts on human resources. Included in evaluation procedures would be the need for effective monitoring techniques. This would include guidance on sampling procedures, equipment, and design as well as analytical procedures that could be tailored to the specific objective of a monitoring effort. These procedures are essential in documenting water quality or biological impacts associated with a REMR activity.

Problem Assessment

The costs associated with environmental problems that are attributable to REMR activities are very difficult to quantify in monetary terms. Obviously, if a no action alternative is selected, then there are no adverse impacts; however, the benefits that may be accrued by a specific REMR activity are foregone. This assumes, of course, that there is no adverse impact associated with the present project (e.g., continuation of present project operation) that will be eliminated by the REMR activity. While elimination of an environmental impact is not generally a specific objective of a REMR activity, there are many cases

(i.e., addition of selective withdrawal) where a tangible environmental benefit is possible.

The general nature of impacts to be expected from REMR activities has been discussed previously and ranges from alterations in water quality to loss of biological resources. A decision to proceed with a specific REMR activity in the face of documented adverse impacts can result in environmental costs regardless of the other benefits associated with the project. When uncertainty exists with respect to environmental impacts, the decision to proceed can result in significant environmental costs depending on the specific circumstances.

Costs attributable to adverse environmental impacts can generally be classified as direct or indirect. Indirect costs are those that result from litigation, adverse public reaction, loss of aesthetic value, or a myriad of other socioeconomic consequences as a result of the REMR activity. These indirect costs can lead to direct costs, but are generally viewed as a reaction to or an intangible loss perceived to occur as a result of a REMR activity. Direct costs that can occur as a result of environmental problems result from project-specific studies or restudies, legal, project modification, delays, loss of project benefits, and increased operational costs. In almost all cases these costs are attributable to corrective actions required or project delays. In the case of REMR activities the most significant cost will generally result from a delay in the activity that in turn can be reflected in increased operation and maintenance costs associated with the original problem or a delay in realizing increased project benefits from an addition of a purpose or change in operation. The lack of thorough evaluation of the environmental consequences of a REMR activity can lead to a poor decision with the consequence of significant additional costs, which can dramatically affect the benefits of a REMR activity.

Previous Research

The Corps has been engaged in research to solve mission related environmental problems for approximately 15 years. During this time,

specific studies such as the Environmental Impact Research Program (EIRP), the Dredged Material Research Program (DMRP) and related efforts under the Dredging Operations Technical Support (DOTS) Program, the Environmental and Water Quality Operational Studies (EWQOS) Program, the Aquatic Plant Control Research Program (APCRP), the Recreation Research Program (RRP), and others that have produced a large amount of technology to solve environmental problems. While a majority of this research has not been specifically directed at problems unique to REMR activities, a portion of this knowledge will be directly applicable to these problems. Examples of information that are applicable include water quality models from EWQOS, restoration techniques from EIRP, aquatic plant control technology from APCRP, and carrying capacity models from RRP. This does not imply that all environmental problems associated with REMR activities can be addressed in this fashion, but rather that a large technology base exists that can be brought to bear on these problems or at least serve as a sound basis for subsequent research.

Proposed Research and Development

Coordination between environmental research and other research in the REMR program will have to be extremely close for three reasons:

a. To ensure that previous and ongoing environmental research is effectively used within the REMR program, thus avoiding any duplication.

b. To recommend alternative designs or environmental features for REMR activities to meet environmental objectives.

c. To identify environmental and water quality considerations as soon as possible during the development of REMR technology.

Exact definition of environmental research within the REMR program is difficult until the precise nature of other REMR research is known; however, from the present analysis of problems two general areas may be defined. These areas involve:

a. Evaluation of environmental and water quality considerations associated with REMR activities.

b. Technology to meet environmental objectives consistent with the goals of REMR activities.

The first task will be oriented at developing or adopting existing technology to evaluate water quality and biological impacts associated with REMR activities. This will include appropriate guidance on monitoring the environmental effects since this information can be used to verify techniques and provide the basis for subsequent improvement. In many cases, for example water quality modeling, it is expected that existing models can be adapted to solve problems associated with REMR activities. In some cases, additional research may be required, for example, to address the water quality impacts of materials used for repair or maintenance if their reaction, leachability, toxicity, or durability in an aqueous environment is not known. In a similar fashion, biological impacts may be extrapolated from known information with specific research requirements dependent on the site and type of REMR activity employed.

The second task will involve development of techniques to reduce the adverse environmental impacts of REMR activities. Emphasis will be placed on technology that maximizes environmental benefits while keeping costs at a minimum and maintaining consistency with the objectives of specific REMR activities. The scope of technology to be provided from this research task includes alternative designs and construction procedures to meet REMR objectives, addition of specific environmental features to reduce impacts, and restoration techniques. Since the impacts associated with most REMR activities are confined to the activity, emphasis will be placed on measures to reduce impacts during and after construction.

Technology Transfer

Results of environmental research within the REMR program will most likely be incorporated in any engineering or operational guidance developed for specific REMR activities. This disposition will ensure that results are easily accessible to users of REMR technology and are

oriented to the specific task under consideration. The Environmental Engineering Manual series, presently under development, plus available references from environmental research is expected to provide a ready source of background information on the environmental and water quality considerations related to REMR. Technical reports on research related to the environmental aspects of specific REMR activities will also be produced. Additional technology transfer procedures, such as the use of Engineer Technical Letters and involvement in training courses, will be used to further disseminate technology and provide guidance on its use.

PART IX: OPERATIONS MANAGEMENT

Problem Description

There are two ways to manage programs such as REMR: resources can be distributed in accordance with the perceived needs of each agency, or a central agency can establish uniform evaluation procedures with a resulting prioritization of the work based upon the existing condition and the predicted remaining life of the structure. It is proposed that the latter method be adopted and a centralized computer-aided management system be developed for the REMR Program.

If centralized management with the capability for prioritization is not established, it is conceivable that the repair of some structures may be delayed to the point that rehabilitation will be impossible and more costly replacement required. Or even worse, catastrophic failure may take place.

It is not possible to estimate the resources, both dollars and manpower, that can be conserved through implementation of a management system for REMR. However, previous related activities have shown a 50 percent reduction in management costs and substantial reductions in repair and maintenance costs due to a more astute allocation of funds.

A system that has been designed to solve problems similar to those anticipated in the REMR program is called "PAVER" for Pavement Maintenance Management System (Shahin 1980, Kohn and Shahin 1982). It is presently being used by the Air Force and is in the process of being adopted by the Army. This system, though not directly applicable to REMR, can serve as a framework for the development of a REMR Management System.

Problem Assessment

At the present, the Corps does not have an automated centralized management system for maintenance and repair of Civil Works projects. Optimum utilization of resources is difficult to attain without uniform procedures for evaluating the present condition of structures and for

accurately predicting the remaining service life, and without a method for prioritizing the work so that rehabilitation is performed in the order of need. In addition, a centralized data base, accessible to all Corps Divisions/Districts, would provide support for the rehabilitation activities of each office and promote the technology transfer that is an important aspect of a successful REMR project.

The REMR Management System (REMR-MS) will require the development of the following:

a. Uniform evaluation procedures.

b. Methods for determining a condition index and for predicting the remaining service life of structures and equipment.

c. Maintenance and repair guidelines with consequence models.

d. Economic analysis procedures with life cycle costing.

e. A computerized data management process.

The end product will be a computerized management system, with an operations manual and a technical report.

SECTION C
RESEARCH REQUIREMENTS AND BENEFITS

PART I: INTRODUCTION

REMR problems are identified and assessed in Section B of this report. Some of the problems identified have already been solved, and some of them are not researchable. In this section, a research program which will contribute greatly to the ability of the Corps of Engineers to repair, evaluate, maintain, and rehabilitate its Civil Works projects is presented.

This recommended REMR Research Program has had input from each Corps District and Division, the R&D Laboratories, and OCE. In addition, input has been obtained from the Tennessee Valley Authority, Bonneville Power Authority, and Bureau of Reclamation. The results of the recommended research program will be of use to each of these organizations as well as to foreign governments, state and local governments, and private industry.

Technical societies such as the American Concrete Institute and the American Society of Civil Engineers have expressed a desire to be kept informed on the progress of the research. Technical staffs of the Corps Districts and Divisions have expressed desires to participate in the ongoing technical research reviews and to serve on the technical review team.

It is anticipated that the existing staffs of the R&D Laboratories will perform approximately 65% of the recommended program, while approximately 35% will be contracted to either universities or private industry.

The proposed funding for the program is shown in Table AIII-1 in Section A. The work units are shown in order of priority under each task.

PART II: CONCRETE AND STEEL STRUCTURES

Scope of Research

Basically, the success of any maintenance and repair measures depends upon two factors: first, the accuracy with which the cause and extent of the deterioration/damage has been evaluated; and second, the quality of the judgment that has been used in selecting an appropriate maintenance or repair method. Once a specific conclusion as to the cause and extent of damage has been reached, then and only then can a rational selection be made among alternative maintenance and repair strategies. Lack of systematic procedures for evaluating concrete and concrete and steel structures can have these results: repairs may be made when none are required, the maintenance or repair material selected may be inappropriate for the particular application and fail within a short period of time, or the repair procedure may result in increased deterioration of the original concrete. It is evident then that comprehensive techniques and equipment need to be developed to accurately and efficiently evaluate the condition of both concrete and steel as materials and the structure overall. In this research area, particular emphasis will be placed on development of equipment and procedures for underwater inspection and evaluation of a variety of structures. Development of improved nondestructive testing techniques for determining the condition of structures and components and procedures for predicting their remaining service life will also be emphasized.

A great deal of maintenance and repair work has been accomplished within the Corps of Engineers in recent years. However, there is very little documentation available on the performance of the materials and techniques used. Reasonable acceptance criteria will be developed for the different classes of maintenance and repair materials to allow objective evaluation prior to their use in the field. Once these evaluations are made, a centralized clearinghouse will be established where Districts can obtain recommendations as to products and techniques for performing specific types of maintenance/repair. New materials and

techniques for maintenance and minor repairs will be developed as necessary. Protective coatings, expedient concrete patching systems, crack repair techniques, joint maintenance materials, and surface preparation techniques will be emphasized. Detailed guidance will be developed for field personnel on how to select appropriate maintenance materials, and step-by-step instructions will be developed for application of the most frequently used techniques.

Periodic inspection reports for the Corps' 596 structures will be reviewed to develop input data for a computerized data base which will allow improved identification, examination, and evaluation of trends in deterioration and other problems in concrete structures. Once existing inspection reports have been reviewed and entered into the system, an analysis will be performed to determine the most prevalent types of problems and those which could benefit from research. Problem areas already identified which require laboratory and field testing include repair of erosion-damaged concrete, development of underwater concrete repair materials and techniques, evaluation of concrete removal techniques, joint repair and reconstruction procedures, development of improved systems for repair and rehabilitation, bridge deck repair techniques, and systems for improved structural stability. In each instance, detailed guidance will be developed for field use in selection of materials and techniques for efficient and durable repair and rehabilitation of concrete structures exposed to a variety of environments.

Structure surveillance and monitoring systems and devices serve the purposes of assessing the adequacy of design and providing indications of adverse performance. The latter is of primary importance because it directly affects the public safety and welfare. The feasibility of structure monitoring systems based on instrumentation available in most structures will be investigated. In addition, a system employing distance measurement will be evaluated. Recent advances in the fields of instrumentation and automatic data processing will be investigated to determine their potential in structural monitoring and surveillance. Also, new instrumentation and inspection techniques will be developed to supplement periodic inspections and predict service life.

The tasks and work units in the research area are shown in the following. Within each task, the work units are listed in order of proposed priority.

<u>Task A:</u> Evaluation of Concrete and Steel Structures

- <u>Work Unit 1.</u> Underwater Survey Techniques
- <u>Work Unit 2.</u> Nondestructive Evaluation of Deteriorated Metal Structures
- <u>Work Unit 3.</u> Improved Nondestructive Testing Techniques
- <u>Work Unit 4.</u> Structure Damage Index to Determine the Remaining Life and Reliability of Metal Structures
- <u>Work Unit 5.</u> Methods for Assessing the Condition of Deteriorated Structures

<u>Task B:</u> Maintenance and Minor Remedial Measures

- <u>Work Unit 1.</u> Evaluation of Existing Maintenance Materials and Methods
- <u>Work Unit 2.</u> Protective Coatings for Concrete
- <u>Work Unit 3.</u> Development of Improved Maintenance Materials and Methods
- <u>Work Unit 4.</u> Maintenance and Repair of Concrete Shore-Protection Systems

<u>Task C:</u> Repair and Rehabilitation

- <u>Work Unit 1.</u> Repair of Erosion-Damaged Structures
- <u>Work Unit 2.</u> Techniques for Underwater Concrete Repairs
- <u>Work Unit 3.</u> Techniques for Removal of Deteriorated Concrete
- <u>Work Unit 4.</u> Rehabilitation of Navigation Locks
- <u>Work Unit 5.</u> Surface Treatments for Deteriorated Concrete
- <u>Work Unit 6.</u> Improved Repair Materials and Techniques
- <u>Work Unit 7.</u> Techniques for Joint Repair and Rehabilitation
- <u>Work Unit 8.</u> Systems for Improved Structural Stability

<u>Task D:</u> Surveillance and Monitoring

- <u>Work Unit 1.</u> Development and Evaluation of Continuous Monitoring Systems for Structural Safety
- <u>Work Unit 2.</u> Improved Field Inspection Techniques and Equipment
- <u>Work Unit 3.</u> Improved Instrumentation for Older Structures

Table CII-1 at the end of this part summarizes the funding levels to accomplish the research.

Task A: Evaluation of Concrete and Steel Structures

Work Unit 1: Underwater Survey Techniques

Dewatering of many projects or appurtenant structures to perform inspections is difficult, very expensive, and in some cases, practically impossible. In any case, the disruption in project operations associated with dewatering of most structures cannot be tolerated for sufficient lengths of time to conduct detailed surveys and examinations.

The objective of this work unit is to develop accurate and relatively inexpensive underwater survey systems by which a comprehensive assessment can be made concerning the extent of damage and the need for repair of a structure. Areas of research will include surface cleaning equipment, damage detection techniques, sampling and testing methods.

Cleaning marine growth from the underwater portions of concrete structures is almost always required to facilitate inspection and detection of deficiences. A wide variety of tools ranging from a diver's knife or hand tools to high-pressure water blasters are available for cleaning. The advantages and limitations of each will be determined for potential application to Civil Works structures.

In addition to visual and tactile examination by divers, other detection methods including closed-circuit underwater television cameras, video tape recorders, a variety of still cameras, and nondestructive testing techniques (ultrasonics, computerized tomography, etc.) will be evaluated. The use of remotely controlled equipment in order to avoid the need for divers to work in hazardous conditions will be investigated. Systems and technology applicable to mapping and profiling of surfaces underwater (airborne laser systems, acoustic profilers, downward-looking radar, etc.) will be investigated. New equipment or improved uses of existing equipment will be developed for sampling and in situ testing of concrete underwater.

The levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
50	200	200	150	150		750

Work Unit 2: Nondestructive Evaluation of Deteriorated Metal Structures

The obj ctive of this work unit is to develop nondestructive testing techniques and procedures for determining the extent of damage to metal structures caused by corrosion. Existing nondestructive testing equipment that uses acoustic emission and electrical polarization will be modified for application to Civil Works structures. Maintenance and repair costs will be greatly reduced once the condition of deterioration a metal structure has undergone is precisely known. This evaluation will also permit a more meaningful prioritization of the work and provide information on whether the structure should be replaced or rehabilitated.

Levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
100	100	50				250

Work Unit 3: Improved Nondestructive Testing Techniques

Standard methods of structural evaluation such as visual inspection, limited coring, and testing provide general, selective data on material properties and the condition of a structure. However, the restrictive nature and economics of such techniques negate comprehensive technical evaluations. The objective of this work unit is to develop nondestructive tests for in situ structural evaluation.

Current technology which will be investigated for potential application in in situ evaluation includes laser/ultrasonic holography, ultrasonic pulse-echo, dynamic deflection, radiographics, acoustic emission, electrical resistivity, impulse-radar, infrared, and eddy currents.

Areas where additional development is required include transducer design and evaluation, stress wave generation, signal enhancement and processing, and data storage and analysis.

Technology developed in this work unit can be used to nondestructively detect the presence, depth, and extent of rebar, cracks, or inferior quality material within concrete structures, locate voids within or underneath structures, and determine in situ structural stability.

The levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	50	150	150	150	100	600

Work Unit 4: Structure Damage Index to Determine the Remaining Life and Reliability of Metal Structures

The objective of this work unit is to develop a damage accumulation model for structures, based on their load history and environment, capable of predicting remaining life and probability of reliable operation. A "bathtub" curve describes failure rate during service life for many engineering components. Its three parts describe (a) a high initial failure rate as inadequate parts fail, (b) a much lower, steady state rate characterizing most of the useful life, and (c) a dramatic increase in the failure rate as components wear out near the end of their life. By determining where on the life curve a structure and its subsystems lie, the maintenance necessary to ensure continued reliable operation can be determined. This will be accomplished in two ways: First, the structure will be analyzed to determine where on its life curve it falls. Then, a nonarbitrary evaluation of the subsystems will be conducted, based on continuity and damage mechanics, to determine the amount of damage they have sustained. Initial studies will be directed toward pintles and tainter gate tensioning bolts.

This research will result in an evaluation of life remaining and permit major repairs to be made when necessary and convenient, rather than being performed at an arbitrary rate. It will also result in

improved performance and lowered costs, as repairs can be planned and scheduled to provide more reliable service.

Funding levels are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	50	100	50			200

Work Unit 5: Methods for Assessing the Condition of Deteriorated Structures

There are a number of mechanisms that can produce premature deterioration of concrete. The fact that these mechanisms often occur in various combinations within a given structure makes the evaluation process even more difficult. The objective of this work unit is to develop clear and concise guides for accurate determination of the cause and extent of concrete deterioration/damage and its effect on the ability of a structure to perform its intended functions.

Study areas include development of a guide providing standard definitions of terms associated with concrete including examples of the visual manifestations of the various types of deterioration, development of a comprehensive classification system for concrete deterioration to allow correlation of concrete quality and durability between structures, development of improved techniques for locating and tracing cracks within structures, development of guides to determine the significance of the various types of cracking, development of new or improved use of existing equipment to determine in situ material properties, development of equipment and criteria for evaluating masonry structures, and development of techniques to evaluate the service life of a structure.

Once the technology for accurately determining the condition of a concrete structure, particularly the cause and extent of damage, is developed, then rational selections can be made among alternative maintenance and repair strategies.

The levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
			100	100	100	300

Task B: Maintenance and Minor Remedial Measures

Work Unit 1: Evaluation of Existing Maintenance Materials and Methods

To alleviate project downtime due to maintenance and repair, there is an expanding interest in materials for rapid repair/maintenance of concrete and steel. Industry has been aware of this potential market for some time and personnel responsible for concrete maintenance have been flooded with offers of "miracle" materials. Many of these materials are adequate for some situations, provided they are used within the limitations of exposure recognized and expressed by the supplier; some may be of little merit. Others may be inappropriate for general use because they are too expensive or they lack durability. The objective of this work unit is to evaluate these materials and establish a centralized clearinghouse where field offices can obtain recommendations as to products and techniques for performing specific types of maintenance/repair.

Based on systematic evaluations of existing materials, reasonable acceptance criteria will be developed for the different classes of repair materials. Surface preparation techniques will be evaluated to determine which techniques should be adopted for specific types of maintenance and repair materials. The effectiveness of rapid-setting, cast-in-place materials for patching concrete will be evaluated. Joint sealant materials and application techniques will be evaluated to determine which ones are more serviceable. Detailed guidance will be developed for field personnel on selection of maintenance/repair techniques for control of concrete cracking. Also, step-by-step instructions will be developed for application of the most frequently used techniques. Backing materials for quoin and miter blocks will be evaluated to determine material properties and provide a basis for improved specifications.

The levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
50	150	150	150	150	150	800

Work Unit 2: Protective Coatings for Concrete

Many of the Corps' older concrete structures require action to protect them from chemical attack, weathering, erosion, etc., to prevent eventual destruction of the existing concrete. One approach is to coat the concrete with a material that is more resistant to phenomena which are causing deterioration of the original concrete. The Corps has used various coatings in the past, and some have been successful where others have failed. The objective of this work unit is to evaluate the durability of currently available coatings.

Concrete previously protected by chemical coatings will be examined and evaluated to determine reasons for success or failure of the coating. Based on this review, research will be initiated as necessary to develop a guide for selection of protective coatings for use in a variety of aggressive environments. Detailed application procedures will be developed for the more durable, less expensive coatings. Conventional shotcrete as a protective coating will be investigated to establish quality control tests, allowable variations in procedures and materials, and methods to entrain air where air entrainment is required for durability. The feasibility of using a variety of small shotcrete guns for repair of small areas of damage and routine maintenance activities will be investigated. Skid-resistant overlays for older Corps structures will be developed to alleviate slippery operating conditions.

The levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	150	150	100			400

Work Unit 3: Development of Improved Maintenance Materials and Methods

There are a number of materials and methods available for maintenance of concrete and steel structures. Based on manufacturers' claims, there should be an existing product(s) suitable for any conceivable maintenance situation. Unfortunately, there are many examples where this has not proven to be the case. The objective of this work unit is to develop new and improved materials and techniques for maintenance of concrete and steel.

Recent advancements in concrete technology will be reviewed to identify those materials and techniques with potential applications in concrete maintenance. Areas to be examined include surface preparation techniques, advanced construction materials (concrete-polymer composites, fiber reinforcement, silica fumes, etc.), application techniques (in situ treatments, spray-ups, etc.), and resistance to aggressive environments. Desirable features of a maintenance/repair material include short application time, long service life, suitability over a wide range of temperatures and moisture conditions, and low overall cost. Detailed guidance in selection and use of materials and techniques having the desired characteristics will significantly enhance the Corps capability in maintenance and preservation of its existing structures.

The levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	100	150	150	200	200	800

Work Unit 4: Maintenance and Repair of Concrete Shore-Protection Systems

Today's approach to design and modeling of protective armor schemes considers the individual weight, specific weight, and geometry of the prototype armor. Structural characteristics of the units are not simulated; thus, present model results assume that the prototype units will not be structurally abused or a significant number will not be broken.

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RESEARCH PROGRAM DEVELOPMENT REPORT(U) ARMY ENGINEER
WATERWAYS EXPERIMENT STATION VICKSBURG MS
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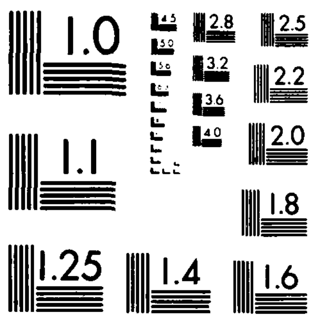

MICROCOPY RESOLUTION TEST CHART
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Recent instances of breakwater damage that may be partially due to broken armor units emphasizes the critical need for additional guidance on the structural abuse that individual concrete armor units can experience before breaking. This gap in knowledge can most effectively be filled by improvements in physical scale modeling. Results of this research would allow maintenance and repair of existing breakwaters with armor units of desired structural characteristics. Other potential benefits include more efficient and economical armor units, lower maintenance cost, safer structures, and ability to reliably predict dollar tradeoffs between initial cost and expected maintenance.

The levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	100	100	100	100	50	450

Task C: Repair and Rehabilitation

Work Unit 1: Repair of Erosion-Damaged Structures

Significant findings in the area of abrasion-erosion resistance have been produced by research conducted as part of the Civil Works Concrete Research Program. For example, fiber-reinforced concrete has been shown to be highly susceptible to abrasion-erosion; its use has been limited through the issuance of an ETL on the subject. The objectives of this work unit will be to continue the previous work on abrasion-erosion resistance and to conduct similar evaluations of different concrete materials for cavitation-erosion resistance. The anticipated end products of this work will be guidance on appropriate materials and repair methods for areas which are susceptible to abrasion-erosion, cavitation-erosion, or both.

In the area of abrasion-erosion resistance, testing of samples produced from underwater repair techniques (tremie or preplaced aggregate concretes) will be conducted. Additional types of surface treatments and various proprietary products will also be evaluated. Limited

work done to date on very high strength concretes (15 to 30 ksi) will be expanded and continued. Monitoring of material performance in prototype structures will be continued.

In the area of cavitation-erosion, an approach similar to that undertaken for the abrasion-erosion study will be initiated - a wide variety of materials will be prepared and tested in the WES cavitation facility. Relationships between concrete strength, aggregate type, surface coatings and treatments, etc., and cavitation resistance will be developed. Based on laboratory test results, selected materials will be used in prototype repairs to observe their performance under actual field conditions.

The levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
50	200	150				400

Work Unit 2: Techniques for
Underwater Concrete Repairs

The capability to accomplish satisfactory repairs underwater, near the waterline, or on wet concrete must be developed. For major repairs such as replacement of abrasion-damaged concrete in a stilling basin, repairing underwater may offer significant savings. For minor repairs such as patching spalled areas, repairing wet or damp concrete may be the only procedure available. The objectives of this work unit are (a) to develop guidance concerning rehabilitation conducted underwater to allow a District to evaluate that option when selecting techniques to be used on a given structure; and (b) to develop the necessary guidance concerning materials, equipment, procedures, inspection, and evaluation to insure that satisfactory results will be obtained if an underwater repair method is selected. Specific areas to be investigated are described below.

a. The use of tremie concrete and preplaced aggregate concrete to repair abrasion damage in stilling basins will be evaluated. Data concerning relative abrasion-erosion resistance of these concretes will be developed. Construction procedures and equipment will be developed.

b. Various products for repairing cracks, patching spalls, attaching dowels, bolts, etc., or any other underwater maintenance and repair task will be evaluated. This work will lead to approved products and techniques and will be closely coordinated with the work in Work Unit 1, Task B, above.

c. The use of precast concrete elements and prefabricated steel elements to accomplish repairs underwater will be investigated. Situations in which these elements could be used will be determined.

d. Techniques for monitoring and evaluating repairs made underwater will be examined. This work will be coordinated with related work on Underwater Survey Techniques and Nondestructive Testing Techniques.

The levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	200	150	100			450

Work Unit 3: Techniques for
Removal of Deteriorated Concrete

In a review of concrete removal techniques (Campbell, 1982) explosive blasting was shown to be the most economical technique. Yet, there are many instances in which due to considerations of damage to remaining concrete or mechanical items explosive blasting cannot be used. The objective of this work unit will be to conduct testing of selected concrete removal techniques to determine if they merit recommendation to District offices as alternatives to explosive blasting.

Techniques which would be evaluated include acetylene-air rockbreaker, concrete splitter, expansive agent, high-pressure carbon dioxide blaster, and high-pressure water jet (in situations where reinforcement is to be preserved for reuse). Also, a borehole notching technique appears to enhance the performance and crack control for some means of removal, such as explosive blasting and expansive agents, techniques that require boreholes.

These removal techniques would be evaluated in the laboratory to develop basic performance criteria. However, the majority of the test program would involve field testing as a part of scheduled repair and

rehabilitation work at Corps projects. The principal determinations to be made for comparison would be:

a. Cost.

b. Removal rates.

c. Extent of damage to concrete that remains.

d. Problem areas.

The levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	150	150	150	50		500

Work Unit 4: Rehabilitation of Navigation Locks

Experience gained during rehabilitation of a number of structures indicates that techniques associated with new construction are often not successful when used in a repair/rehabilitation role. Similarly, experience gained through the research done to date has shown that there is a potential for significant savings through laboratory and field studies of various techniques prior to field implementation. Recent and current rehabilitation projects involving Corps navigation locks will be reviewed and analyzed. Design and construction methods, materials, costs, and quality of finished products will be examined to provide guidance for future rehabilitation projects and to determine areas which could benefit from research. Problem areas already identified include the following:

a. Anchoring replacement concrete to existing structures. Dowels, bonding agents, and long-term performance will be examined.

b. Cracking in replacement concrete. Relatively thin replacement sections are extremely susceptible to cracking. Causes and cures will be investigated.

c. Effects of vibration caused by operation of the structure during repair/rehabilitation. The question of whether such vibration affects the repair materials will be investigated.

d. Precast concrete applications. Since precast concrete can be produced under tightly controlled conditions, very high quality products may be expected. Possible uses for precast elements during typical rehabilitation projects will be investigated.

e. Roller-compacted concrete applications. Possible uses for this cost-effective material during rehabilitation will be developed.

f. Lock gates. Techniques to minimize or eliminate interference with gate operation caused by wear within the pintle system will be developed. The shape of quoin blocks and location of the contact surface in relation to the pintle will be optimized. Lubrication techniques will be evaluated to determine optimum protection systems.

The levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	180	180	100	100	50	610

Work Unit 5: Surface Treatments for Deteriorated Concrete

Surface treatments such as conventional shotcrete offer fast and usually economical means of replacing deteriorated concrete. Yet shotcrete has not performed well in several past rehabilitation projects. Poor materials, poor workmanship, lack of surface preparation, and lack of entrained air in the shotcrete are a few of the problems that have resulted in poor quality work. Guidance will be developed on the appropriate use of conventional shotcrete for repair or rehabilitation. Also, other types of shotcrete including latex modified cements and polymers will be investigated. Potential applications for fiber-reinforced shotcrete will also be investigated.

Other surface treatments such as cement and polymer mortars, epoxy resins, expansive cements, and various concrete sealers will be evaluated to determine their potential in arresting concrete deterioration. Each surface treatment will be examined to ensure that they perform as intended in a given environment and do not increase the rate of deterioration beneath the treated areas.

The levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	100	100	100	100		400

Work Unit 6: Improved
Repair Materials and Techniques

A major part of repair costs is due to the necessity for removing substantial portions of deteriorated concrete and replacing with new concrete. The objective of this work unit is development of materials and methods which will allow in situ treatment of deteriorated concrete without the necessity for removal. The use of polymer/epoxy materials in such applications appears to have potential.

Major areas of research include development of monomers with sufficient viscosity to achieve good penetration in small cracks and development of impregnation techniques (injection/vacuum) which are applicable to a variety of hydraulic structures. Such materials and techniques will allow deep impregnation of large field structures with a minimum of labor, materials, and operational difficulties.

The levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	100	100	100	150	200	650

Work Unit 7: Techniques for
Joint Repair and Rehabilitation

Waterstops along the joints of a number of structures have failed due to improper installation, deterioration with age, improper design for . .ual service conditions, or service conditions not normal to the structure. Also, tilting of navigation lock monoliths has caused rupturing of waterstops between individual monoliths in a number of structures. In addition, concrete deterioration along monolith joints is generally more severe than in other areas of hydraulic structures. The objective of this work unit is to develop basic repair/replacement materials and techniques which can be adapted to a variety of joint repair situations.

Drilling techniques and materials for lining and sealing the drill hole will be evaluated for use in installation of replacement waterstops within monoliths. Also, techniques to install replacement waterstops along the concrete face will be developed and evaluated. Materials and

techniques for reconstruction of monolith joints will be developed. Areas of consideration include type and extent of concrete removal, joint configuration, and replacement materials (armor, polymer concrete, fiber concrete, etc.).

The funding levels are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	100	150	100	50		400

Work Unit 8: Systems for
Improved Structural Stability

Structural stability involves the stability of the entire structure against sliding or overturning as well as the stability of individual components which may be cracked or otherwise damaged. The objectives of this work unit are as follows:

First, to review the stability criteria used for existing structures. Since the structures are obviously stable, is it necessary to bring the structure up to meet present-day criteria during rehabilitation?

Second, to review techniques for increasing structural stability when required. The usual technique is to posttension the structure to the underlying foundation. This procedure is expensive and can cause additional problems. Alternative techniques will be examined.

Third, to examine techniques used for increasing or reestablishing the stability of individual structural elements. Posttensioning systems or rock anchors are usually used for this type of work. A wide range of anchor types, drilling techniques, anchor installation procedures, grout mixtures and injection techniques, stress equipment and protection systems have been utilized on Corps projects. Since anchors of some type are required on almost all rehabilitation projects, previous work will be reviewed to identify those techniques which have been most successful for application in future work.

Fourth, to investigate the need for techniques to monitor or evaluate the performance of systems used to improve structural stability. If

the stability of a structure depends upon a posttensioning system, for example, there should be a method to evaluate the long-term performance of that system.

The funding levels are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
			100	150	350	600

Task D: Surveillance and Monitoring

Work Unit 1: Development and Evaluation of Continuous Monitoring Systems for Structural Safety

The potential for destruction resulting from a dam failure has created significant interest in the development of instrumentation capable of automatically monitoring a large dam and providing advance warning of a failure. Given enough time, the structure could be repaired and stabilized, the water level of the reservoir lowered, or the people and property below the dam evacuated. The objective of this work unit is to develop systems capable of automatically monitoring the behavior of hydraulic structures.

The feasibility of structural monitoring systems based on instrumentation already existing in most structures (stress and strain meters, joint meters, piezometers, inclinometers, flow meters, etc.) will be investigated. Requirements for new instrumentation specifically for monitoring and surveillance will be developed. Surveying techniques including highly accurate laser distance meters will also be investigated for application in structural monitoring. Based on laboratory development and testing, the hardware and software for a prototype system will be constructed and evaluated in an actual monitoring environment.

The funding levels are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	200	200	200			600

Work Unit 2: Improved Field
<u>Inspection Techniques and Equipment</u>

Current structural inspection techniques rely heavily on visual examination. If visual examination of the concrete surface indicates possible problems, a more detailed evaluation of those specific parts of the structure is generally in order. In most cases this involves coring of the concrete which is time-consuming, costly, and destructive. The use of available nondestructive methods is often limited in scope and reveals little about the in situ performance capability of the structure. The objective of this work unit is development of systems that will allow in situ, nondestructive, real-time evaluations of overall structural condition and integrity.

Resonance techniques appear particularly applicable to field inspection because the vibration parameters are a function of modulus of elasticity, boundary restraints, and continuity. Using such a technique, the characteristic vibrational signature of a structure could be evaluated at selected time intervals to supplement periodic inspections and estimate remaining service life.

The funding levels are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
			100	150	150	400

Work Unit 3: Improved Instru-
<u>mentation for Older Structures</u>

The Corps presently maintains over 500 operating dams and a variety of instrumentation devices play a principal role in assuring their continued safe performance. During the initial reservoir filling and periods of higher water stages the instrumentation is generally read on a daily basis. During normal operation, instrumentation is usually read once a month. Considering that a major dam may have 1500 to 2000 instruments, the magnitude of data collection, verification, reduction, and analysis is obvious. The objective of this work unit is to develop improved procedures for handling massive amounts of data, also, to develop

new instrumentation or improved uses of existing instrumentation for older structures where original instrumentation has failed or is no longer adequate.

In recent years, the great advances made in the field of instrumentation and automatic data processing have opened up new possibilities for systematic collection and interpretation of a variety of measurements. Automatic data acquisition systems and microcomputers appear particularly applicable for real-time collection, processing, and storage of measurement data. Such equipment will be investigated to determine its potential in monitoring and surveillance of Corps' structures. Instrumentation technology has progressed logarithmically in the past two decades. Techniques for engineering measurement (electronics, lasers, vibration technology, etc.) have become quite sophisticated and accurate. The feasibility of applying this technology to replace outmoded instrumentation associated with the Corps older structures will be investigated.

The funding levels are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
				170	200	370

Table CII-1

Summary of Funding Levels

Concrete and Steel Structures Research Area

Work Unit	84	85	86	87	88	89	Total
	Funding for Cited Fiscal Year, $1000's						
Task A: Evaluation of Concrete and Steel Structures							
1. Underwater Survey Techniques	50	200	200	150	150		750
2. Nondestructive Evaluation of Deteriorated Metal Structures	100	100	50				250
3. Improved Nondestructive Testing Techniques		50	150	150	150	[illegible]0	600
4. Structure Damage Index to Determine the Remaining Life and Reliability of Metal Structures		50	100	50			200
5. Methods for Assessing the Condition of Deteriorated Structures				100	100	100	300
Task Totals	150	400	500	450	400	200	2100
Task B: Maintenance and Minor Remedial Measures							
1. Evaluation of Existing Maintenance Materials and Methods	50	150	150	150	150	150	800
2. Protective Coatings for Concrete		150	150	100			400
3. Development of Improved Maintenance Materials and Methods		100	150	150	200	200	800
4. Maintenance and Repair of Concrete Shore-Protection Systems		100	100	100	100	50	450
Task Totals	50	500	550	500	450	400	2450
Task C: Repair and Rehabilitation							
1. Repair of Erosion-Damaged Structures	50	200	150				400
2. Techniques for Underwater Concrete Repairs		200	150	100			450

(Continued)

Table CII-1 (Concluded)

Work Unit	Funding for Cited Fiscal Year, $1000's 84	85	86	87	88	89	Total
3. Techniques for Removal of Deteriorated Concrete		150	150	150	50		500
4. Rehabilitation of Navigation Locks		180	180	100	100	50	610
5. Surface Treatments for Deteriorated Concrete		100	100	100	100		400
6. Improved Repair Materials and Techniques		100	100	100	150	200	650
7. Techniques for Joint Repair and Reconstruction		100	150	100	50		400
8. Systems for Improved Structural Stability				100	150	350	600
Task Totals	50	1030	980	750	600	550	4010
Task D: Surveillance and Monitoring							
1. Development and Evaluation of Continuous Monitoring Systems for Structural Safety		200	200	200			600
2. Improved Field Inspection Techniques and Equipment				100	150	150	400
3. Improved Instrumentation for Older Structures					170	200	370
Task Totals		200	200	300	320	350	1370
Area Totals	250	2130	2230	2000	1770	1550	9930

PART III: GEOTECHNICAL--SOILS SUBAREA

Scope of Research

A research task is planned for each problem category described in Section B, Part III. Accomplishment of the research in each task will improve REMR efforts with respect to soils features of existing Civil Works projects and provide a sound basis for decisions when significant REMR action becomes necessary in the future. The high-priority work units are as follows:

Task A: Remedial Improvements

- Work Unit 1. Rehabilitation Alternatives to Control Levee Underseepage
- Work Unit 2. Improvement of Foundation Soils Susceptible to Liquefaction
- Work Unit 3. Remedial Cutoffs and Control Methods for Adverse Seepage in Embankment-Dams and Soil Foundations

Task B: Evaluation of Soil Conditions and/or Performance

- Work Unit 1. Allowable Movements and Performance Criteria

Task C: Maintenance of Soil Features

- Work Unit 1. Restoration of Drainage Systems
- Work Unit 2. Restoration of Relief Wells
- Work Unit 3. Methods for Maintaining Wells and Seepage Control in Cold Regions
- Work Unit 4. Geotechnical Applications for Soil Erosion Control and Slope Stabilization
- Work Unit 5. Erosion Control in Cold Regions

Table CIII-1 at the end of this part summarizes the funding levels to address these high-priority work units for the soils research subarea.

Task A: Remedial Improvements

Some problems of an extensive or serious nature cannot be resolved

by conventional or even by improved maintenance practices. This research task will provide operating forces the widest possible choices in alternatives for cost-effective improvements that will restore or maintain the functional capability of the project or specific soils feature.

The research will develop the special requirements necessary to implement remedial measures and will provide the technology and guidelines for project applications. The research will address particular problems and alternative solutions; demonstrations and implementation will be site-specific and project-funded. The research will examine the technical merits, relative cost factors, limitations, and influences of various solutions with respect to the project. The principal technology transfer will be immediate and direct liaison with affected projects. Interim guidelines will be available for experimental improvements; general guidelines for use in preparing new and/or revised manuals and specifications will be prepared as concepts are reasonably validated.

Work Unit 1: Rehabilitation Alternatives
to Control Levee Underseepage

Seepage related to levees is one of the most prevalent causes of distress. Because of difficulties in identifying minor soils and geological details which may exist in the foundations and uncertainties in seepage predictions, control is frequently accomplished by close observation of a minimal system. This approach requires an effective monitoring system and immediate attention to signs of distress to prevent more serious consequences; e.g., damage from piping. Numerous problems and deficiencies in the state of the art are encountered in assessing alternatives for seepage control. Seepage control berms for levees require excessive rights-of-way and loss of valuable property; positive cutoffs are expensive and may not always be practical; drainage intercepts and impervious barriers pose hazards during installation; relief wells increase maintenance and potential for vandalism; and various types of drains and blankets are only partially effective may require considerable efforts to maintain their efficiency.

Many mainline levees (e.g., those on the upper Mississippi River

and others on alluvial foundations) are presently being rehabilitated to withstand modern hydraulic-hydrology standards. However, current Corps guidelines and procedures for seepage control measures are inadequate and often inconsistent with observed field performance: berm widths based on available standards are excessive and impractical; current procedures fail to accurately discriminate between locations requiring berms and those not requiring berms; and guidelines for field permeability ratios differ substantially from locally determined values. Consequently, new methodology is needed for assessing acceptable seepage levels and for estimating seepage control requirements from pervious levees, with and without berms, on both pervious and impervious foundations. The physics of sand boils and pipeability of foundation and levee soils need to be determined to develop better procedures for evaluating levee underseepage and remedial control systems.

The research will resolve these deficiencies and develop improved user guidelines for seepage investigations, for remedial measures, and for monitoring their effectiveness. The research will develop methods for minimizing and controlling underseepage beneath permeable and impermeable dikes which are subjected to large fluctuations in water levels. Complementary project fundings will be necessary for field support and project demonstrations. The guidelines will be suitable for use in preparing revisions to the EM 1110-2- series and in developing training aids in courses; e.g., the Seepage Course for Embankments and other ad hoc onsite training for project maintenance and District personnel.

Levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
50	150	150	150			500

Work Unit 2: Improvement of Foundation Soils Susceptible to Liquefaction

Some existing Corps earth dams, pumping plants, locks, and other structures on alluvial foundations in areas of existing moderate to

high seismicity require remedial action to improve the earthquake stability of their foundations. Little data exist as to the effectiveness and consequences of different methods to minimize liquefaction susceptibility of foundations of existing structures. In some cases, the only options presently available are: (a) accept the risk of catastrophic failure; (b) decommission of the project; or (c) replace the structure. The research may offer cost-effective alternatives, result in savings of hundreds of millions of dollars and in saving of projects themselves, or provide an absolute basis for choosing one of these options.

The objectives will be to: (a) examine the feasibility of eliminating liquefaction potential of foundation soils under existing structures; (b) evaluate relevant experience; (c) analyze economic and technical feasibility of methods having high potential for effectiveness; (d) develop guidelines for laboratory experiments and field test demonstrations on Corps projects (complementary project funding for actual tests and demonstrations will be necessary); and (e) monitor performance of selected methods on Corps projects.

User products will be: (a) interim guidelines for immediate application to Corps dams where current evaluations reveal serious potential liquefaction problems; (b) final input to EM's, ETL's, EC's; and (c) case histories of tests and demonstrations.

Funding level are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
50	100	100	100			350

Work Unit 3: Remedial Cutoffs and Control Methods for Adverse Seepage in Embankment-Dams and Soil Foundations

Seepage related to embankment-dams is a critical problem. Remedial measures are expensive and may require major reconstruction. Remedial seepage control may require reservoir pooling restrictions until repairs can be implemented; grouting poses potential hydraulic fracturing problems; and positive cutoffs are expensive and not always economically practical, but alternative control measures may be only partially

effective at best.

The technical, economic, and practical limitations of alternative methods for positive cutoffs and/or effective control of seepage through alluvial or channeled foundations and through embankments need to be established, including expedient defensive measures for unacceptable or worsening seepage conditions.

The research will develop conceptual solutions for minimizing and controlling underseepage through earth and rockfill dams and their foundations. General geotechnical guidelines will be prepared for implementation; project-specific guidance and geotechnical counsel will be required for seepage investigations, remedial techniques, and monitoring their effectiveness until the methods have been sufficiently validated on prototype projects. Complementary funding for prototype projects will be necessary for pilot studies or complete demonstrations.

The geotechnical guidelines will be suitable for incorporating in the EM 1110-2- series and for developing training aids in courses; e.g., The Seepage Course for Embankments, the Earth and Rockfill Dams Course, and other adhoc onsite training for maintenance and District personnel.

Levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	100	150	200	250	250	950

Task B: Evaluation of Soil Conditions and/or Performance

This task addresses problems associated with the present functional condition, performance analyses for the past and present, and the predicted performance for anticipated events including modifications or remedial work.

The nature of the problems is quite varied. Only the high-priority uncertainties concerning allowable movements, the validity of criteria related to performance, the soil properties applicable to determining the condition of older structures, and the ability of structures to

withstand unprecedented events are addressed. Evaluations of these problems will provide guidelines on alternatives when a need for preventive maintenance or modification will correct project deficiencies. The research results will provide operating personnel a rational basis for decisions on REMR options. Guidelines will provide reliable cost-effective solutions to problems that have been thoroughly investigated. Unnecessary conservatism because of the unknown will be minimized by determining within the state of the art the true nature of these problems. Other problems identified of lesser immediate concern, but worthy of research when resources become available, involve aging, overtopping, and stability and deformation of embankments and foundations for both static and seismic conditions; and soil-structure interaction with appurtenant structures, including potential problems associated with locating new structures in old flood control levees.

This task involves the problems most difficult to research and for which the benefits may be the least apparent. The research results will provide new perspectives and guidelines for reliable assessment of project conditions and performance.

Work Unit 1: Allowable Movements and Performance Criteria

Embankments and foundations for appurtenant structures and auxiliary facilities are engineered conservatively with a factor of safety which limits movements. Occasionally, when abnormal movements occur, the effect on the structure must be evaluated to determine whether or not remedial action is required. Some older structures do not meet current criteria, yet have shown no signs of movement; thus, the requirement for conformance with current criteria should be validated. Differences between the theoretical conditions used in predicting performance and the conditions applicable to actual performance will be examined to determine the reasonable amount of movements older structures can undergo without a stability or distress problem, taking into account the modes of movements. The difference between normal movements expected for new structures and tolerable movements for older

structures will be determined; this determination is particularly necessary if advanced monitoring and telemetry systems are to be used effectively with automatic alarm thresholds. Appropriate methods of accurately measuring movements will be considered; realistic guidelines for an acceptable level of stability will be developed; past and present criteria will be examined based on analyses of performance of selected structures; and verifiable criteria will be formulated for evaluating the effectiveness of remedial measures to limit movements. Results will aid in the identification of potential stability problems, provide criteria for evaluating the seriousness of problems, and provide guidelines on acceptable and/or tolerable movements. These results will be useful in determining the extended useful life of a structure with and without rehabilitation.

An independent phase of this work unit will examine the most prevalent, recurring, and costly problems encountered on Corps Civil Works projects for which causative mechanisms are not obvious and from which "lessons learned" will enhance the REMR Research Program. The results of investigations and analyses of distress, incidents, or failures will be distributed in case history reports and will provide the basis for developing appropriate improvements to O&M efforts and/or remedial measures.

An effort similar to that which generated the Civil Works Earth Dam Criteria Reports (1960-1974) would involve technical assessment by the responsible District office. The original project investigation report could be an appendix to periodic inspection reports. Broad applications and comparisons with similar REMR projects and relevant R&D would be added by the research staff for Corps-wide distribution. The reports would emphasize the "lessons learned" and the effectiveness of solutions; the Corps would benefit by having previous experience on failures, successful treatments, costs, merits, and limitations readily at hand for application to current problems. The reports could also aid in early recognition of problems and permit preventive maintenance to avoid more serious problems requiring extensive REMR measures. Initially, a screening process would be employeed to emphasize the

more critical problems, problems effecting the most significant savings or benefits, and the most significant technical achievements. The only product anticipated in this phase would be the reports of problems and solutions in an identifiable and cumulative indexed series.

Funding levels are as follows ($1000's):

	FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
Criteria Assessment		150	150	100	100	100	600
Case Histories* (per incident report)		25	25	25	30	30	NA

Task C: Maintenance of Soil Features

This task will develop alternatives to alleviate numerous recurring problems. These problems are often perceived as small in comparision to other more dramatic problems; nevertheless, they can result in significant maintenance costs. If maintenance problems in soil features are not properly corrected, more serious damage may result with major adverse consequences. Since the problems and direct causative factors are frequently apparent, the research can be more specifically oriented. However, the problems may be symptons of more serious problems which must be dealt with; therefore, the research cannot be too narrowly defined or initiated without a thorough examination of all relevant onsite conditions. Improved technical guidance will be suitable for use in preparing or revising operating manuals and regulations. The principal benefit will be reduced maintenance costs.

Work Unit 1: Restoration of Drainage Systems

Drainage systems are critical components for seepage control; their proper functioning must be ensured at all times for safe, reliable structure performance. Several Division offices cited major problems

*Funding is not included in this planning budget but would be considered during the annual program documentation update on a case-by-case basis.

with drains and with piezometers, the most widely used device for monitoring effectiveness of seepage control systems. Drains and underdrains become clogged from time to time due to incrustation from precipitation of carbonates of calcium, magnesium, iron, or maganese; stoppage due to bacterial growth; and stoppage resulting from deposition of silt and/or clay from suspension. Deterioration of clay pipe in drains, metal risers in peizometers, and other man-made materials are also problems. These problems decrease the efficiency of drainage systems and thereby decrease seepage control and increase seepage pressures endangering the stability of embankments and appurtenant structures; e.g., spillways and outlet works.

These systems require regular maintenance, periodic restoration, and at times even replacement. Some of the external systems can be inspected visually; some can be visually examined indirectly (e.g., by television cameras); and others cannot be examined and must be tested to determine their effectiveness. Regular inspection, examination, and testing efforts are manpower intensive, require special equipment, and result in large recurring maintenance expenses. Restoration is even more costly, and replacement can be a difficult and expensive operation. And of course some systems in or under major structures cannot be replaced at all.

Improved procedures are needed for periodic treatment to reduce maintenance costs and the need for restoration, as well as to ensure selection of less costly, longer life materials when replacement is necessary. Improved protection methods for exposed components are needed to deter vandalism. Potential savings are in the millions of dollars spent annually on maintenance and in the form of substantial reductions in replacement costs and extended life cycle for existing and replaced systems.

User products will be better methods and materials for treatment to remove and prevent incrustation; better methods for inspection, testing, and monitoring performance; and better replacement methods and materials. Interim guidelines on current technology will be the first priority. Onsite testing of experimental alternatives and demonstrations

of the use of new methods and materials will be directed at project deficiencies; demonstrations will be an integral part of project maintenance and will be project-funded; independent field tests and demonstrations are not an economical or practical option. Interim guidelines and technical advice will be provided for experimental concepts and monitoring demonstrations. Guidelines will be developed for use in revising appropriate EM's in the 1110-2- series and other relevant operating documents. Similarly, special training aids will be prepared for use in courses (e.g., the Seepage Control Course) or special ad hoc onsite training for maintenance personnel.

Funding levels are ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	150	150	100			400

Work Unit 2: Restoration of Relief Wells

Relief wells are critical components for some seepage control systems, and their proper functioning is essential for reliable structure performance. Relief wells have a great deal in common with drainage systems (see Task C, Work Unit 1) with respect to clogging and deterioration of man-made materials. Relief wells are more accessible for maintenance and restoration and consequently more susceptible to vandalism with attendant requirements for protection and more frequent repair.

The research for relief wells is complementary to that in Task C, Work Unit 1, and has comparable benefits, but potential savings are enormous since the Corps has vast numbers of relief wells. Many problems with relief wells are common to piezometers, but piezometers are inexpensive to replace and though critical from the standpoint of monitoring are not critical to the functioning of the structures.

The user products and research approach will be similar to that for Task C, Work Unit 1. The research could be accomplished independently or concurrently; however, the work units are planned for concurrent performance for maximum mutual cooperative effort.

Levels of fundings are ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	100	100	100	100		400

Work Unit 3: Methods for Maintaining
Wells and Seepage Control in Cold Regions

This work unit is complementary to Work Units 1 and 2 of Task C. Relief wells and seepage control measures are subjected to special problems in cold regions. Freezing and thawing can dramatically change the strength and hydraulic properties of soils, particularly upon thawing which frequently coincides with flood periods. In subfreezing air temperatures, ice hinders or prevents flow of water rendering relief wells ineffective; if this condition is not corrected, the stability of the dam or levee could be endangered. Economical methods are needed for rapidly thawing and maintaining relief wells ice-free.

The research will develop methods to improve performance involving freezing and thawing in seasonal frost and permafrost conditions. Complementary project funding will be necessary for field support and project demonstrations. Guidelines and user products will be comparable to and coordinated with Work Units 1 and 2. Where practical, guidelines will be integrated.

This research could be accomplished independently or concurrently with Work Units 1 and 2, but would be most effectively done concurrently, particularly with Work Unit 2.

Funding levels are ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
		100	100	100	100	400

Work Unit 4: Geotechnical Applications for
Soil Erosion Control and Slope Stabilization

Erosion problems exist in all regions of Corps responsibility. Erosion is associated with different project features including unlined spillways; recreation areas; dispersive clay channel banks and

bottoms, streambanks; docks, piers, and other structures on rivers and lakes; berms and dams subject to overtopping; reservoir slopes and dikes; structures subject to foundation piping and undermining; and structures experiencing piping subsidence and sinkhole development. Erosion is caused by high-velocity flows; rapidly rising and falling water levels; construction and overuse, denuding vegetation; currents and wave action resulting from navigation; rainfall; wind; flooding; seepage and drainage; and other unidentified mechanisms.

Nonstructural treatment, modification, and stabilization methods will be examined to improve soil resistance to erosive forces and to prevent repetitive maintenance. While some of these engineering methods may enhance vegetative protection, the research excludes investigation of vegetation per se. Where nonstructural treatment is not practical or sufficient, structural alternatives to rock will be evaluated. Rock will probably remain the first choice when available because it uniquely meets practically all requirements; however, where not available, new alternatives using man-made products and by-products of industry will be considered, including the auxiliary use of products such as geotextiles in lieu of granular filters. Expanding on the base established under the Streambank Erosion Section 32 Program, which emphasized marginal protection, the emphasis in this study will be on reliable maintenance-free protection to meet project requirements without excessive conservatism.

Specific problems identified by the field offices will be examined to determine causes, mechanisms, types of soils, hydraulic conditions, and erosive forces involved. Maintenance and repair treatments will be investigated, and the most promising will be field-tested at problem sites to determine long-term stability and cost-effectiveness. Complementary project funding will be required for demonstrations in conjunction with normal maintenance.

Practical guidelines will be developed for use in revising existing EM's or preparing a new manual for the 1110-2- series and other relevant operating documents. Similarly, special training aids will be prepared for use in courses (e.g., Streambank Protection) or ad hoc onsite training for maintenance personnel.

Funding levels are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
				100	100	200

Work Unit 5: Erosion Control in Cold Regions

This work unit is complementary to Work Unit 4. Erosion and erosion control measures in cold regions become special problems under winter conditions. Ice and seasonal freezing and thawing accelerate erosion along northern waterways and shorelines, including the Great Lakes. Protection methods (e.g., stone and riprap) suffer from ice damage under winter conditions in the Southwest Division.

The research and user products will be coordinated with Work Unit 4 for continuity. The research may be performed independently or concurrently with Work Unit 4, but cooperative efforts by concurrent research would be advantageous.

Funding levels are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
				100	100	200

Unfunded Requirements

The scope of research (page CIII-1) includes only those problems identified in Part BIII which have been rated high priority for the REMR Research Program, considering a probable limitation of about $4 million for soils-related research during the period FY 1984-1989.

Particular emphasis was given to critical issues, particularly major remedial measures; e.g., for underseepage and liquefaction-susceptible foundations. Major maintenance problems having Corps-wide application were given preference; e.g., seepage control measures and erosion problems are widespread problems. Many of the remaining problems rated as being of medium and low priority could be addressed

by local project funding where the consequences are severe; others could benefit from technology transfer with funding for adapting state-of-the-art technology to site-specific conditions with nominal engineering or applied research effort.

The problems identified in Part BIII, but not included in the initial research program, could be effectively addressed within work units as follows:

Task A: Remedial Improvements

Repair and Rehabilitation Alternatives for Pile-Supported Structures

Task B: Evaluation of Soil Conditions and/or Performance of Foundations

Seismic Stability of Existing Embankments and Foundations

Effects of Aging on Embankments and Foundations

Evaluation of Improvements to Withstand Overtopping

Standards for Installation of Auxiliary Structures in Existing Embankments

Foundation Stability and Settlement of Shore Protection Embankments

Task C: Maintenance of Soil Features

Advanced Technology Geotechnical Monitoring and Reporting Systems

Instability in Reservoirs and Bank Slopes

Roadway Maintenance and Repair Guidelines

Geotechnical Aspects of Maintenance Dredging Disposal

Each of these work units includes related problems identified by different Division offices; each specific problem could be researched

separately, or common problems could be investigated under the common work unit umbrella. Insofar as practical, problems omitted from this initial program will be considered under other programs and by other sponsors; related work by others will be considered for technology transfer when available. Omission from this program does not exclude cursory consideration in conjunction with related activities.

Table CIII-1

Summary of Funding Levels

Soils Research Subarea

Work Unit	84	85	86	87	88	89	Total
	Funding for Cited Fiscal Year, $1000's						
Task A: Remedial Improvements							
1. Rehabilitation Alternatives to Control Levee Underseepage	50	150	150	150			500
2. Improvement of Foundation Soils Susceptible to Liquefaction	50	100	100	100			350
3. Remedial Cutoffs and Control Methods for Adverse Seepage in Embankment-Dams and Soil Foundations		100	150	200	250	250	950
Task Totals	100	350	400	450	250	250	1800
Task B: Evaluation of Soil Conditions and/or Performance							
1. Allowable Movements and Performance Criteria		150	150	100	100	100	600
Task Totals		150	150	100	100	100	600
Task C: Maintenance of Soil Features							
1. Restoration of Drainage Systems		150	150	100			400
2. Restoration of Relief Wells		100	100	100	100		400
3. Methods for Maintaining Wells and Seepage Control in Cold Regions			100	100	100	100	400
4. Geotechnical Applications for Soil Erosion Control and Slope Stabilization					100	100	200
5. Erosion Control in Cold Regions					100	100	200
Task Totals		250	350	300	400	300	1600
Subarea Totals	100	750	900	850	750	650	4000

PART IV: GEOTECHNICAL--ROCK SUBAREA

Scope of Research

The general problems identified in Section B, Part IV, are often complex and overlapping. In many cases, solutions to them will require a cooperative research effort from the disciplines of hydraulics, structures, soil and rock mechanics, geology, and others. Close liaison with the Division offices experiencing specific problems is a necessity to ensure timely delivery of research results that are on target with field needs. In this part, the research needed to help the Division offices address the high-priority REMR problems with respect to rock features of Civil Works projects is identified. Developing and using better REMR methods and materials may postpone the need for major rehabilitation. Evaluation of materials and methods used and lessons learned should make future maintenance simpler and repairs more lasting and cost-effective.

The tasks, work units, and priorities in this research subarea are as follows:

- Task A: Repair of Rock Features
  - Work Unit 1. Grouting Practices for Repair and Rehabilitation of Rock Foundations
  - Work Unit 2. Determination of In Situ Grout Distribution in Structural Foundations
  - Work Unit 3. Repair Practices and Quality Control for Rock Slope Protection
- Task B: Evaluation of Rock Features
  - Work Unit 1. Geophysical Techniques for Assessment of Existing Structural Foundations
  - Work Unit 2. Methodologies for Evaluating Remedial Seepage Control Measures
  - Work Unit 3. Rock Erosion in Spillway Channels
  - Work Unit 4. Location and Long-Term Monitoring of Subsurface Water Movement
  - Work Unit 5. Short-Term Weathering and Degradation of Rock Foundations and Slopes

Work Unit 6. Selection and Inspection of Rock Reinforcement

Work Unit 7. Evaluation of Current Sliding Stability and Deformation Criteria with Respect to the Performance of Aging Foundations

Table CIV-1 at the end of this part summarizes the funding levels for the program to accomplish the research.

Task A: Repair of Rock Features

Work Unit 1: Grouting Practices for Repair and Rehabilitation of Rock Foundations

Standard methods for placing grout for the modification of the mechanical behavior of structural foundations have been derived almost entirely from the activity of grout curtain placement intended for seepage control. Bearing capacity, stiffness, and shear strength enhancement are among the mechanical properties for which rock and soil foundations require rehabilitative enhancement.

State-of-the-art advances in grout chemistry need to be joined with geologic engineering technology to make foundation repairs more effective while maintaining economy of application. Improvements in the use of grout to repair mechanical characteristics of foundations may also be found to be applicable to improving seepage control grout curtain placement and effectiveness. The research will draw upon the fields of grout chemistry, rock mechanics, soil mechanics, geophysics, and geology to provide guidance on the best suited type of grout, prediction of the mechanical interaction of grout with the foundation, and assessing the most expeditious means for placing the grout where it will have the most beneficial effect.

Techniques will be developed to allow project personnel to inject grout more rapidly and economically and with more confidence in its final disposition. Because the work unit will rely heavily on close interaction with field grout placement personnel for information input and technique experimentation, there will be an unusually rapid dissemination of findings to those personnel most in need of them.

The levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
100	150	150				400

Work Unit 2: Determination of In Situ Grout Distribution in Structural Foundations

Injection of grout into structural foundations is an accepted practice of improving the mechanical characteristics of those foundations as well as accomplishing seepage control. The actual grout distribution in the subsurface has seldom been evaluated except by correlating grout, by minimal core sampling, or by observing the long-term behavior of the structure. The desired foundation modification cannot be verified or improved without knowledge of where the emplaced grout actually is distributed. This work unit will establish techniques for locating grout in situ in foundations after, but preferably during, placement.

Grout body exploration efforts used to the present time will be documented and assessed. A methodology advanced beyond reliance on recovered core samples for mapping grout distribution will be developed. This methodology will be surface-based if possible or will utilize a minimal number of boreholes and will be comprised of a suite of geophysical, geological, and rock mechanics techniques. Experience in evaluating remedial grouting at John Day Lock and Dam, Portland District, will provide a beginning point for developing the suite of measurements. Techniques will be adapted to allow operating personnel to evaluate the effectiveness of foundation grout placement during or very shortly after the activity.

The levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	125	125	150			400

Work Unit 3: Repair Practices and Quality Control for Rock Slope Protection

Stone protection blankets and armor (on slopes, breakwaters, dikes, etc.) fail or need to be repaired or replaced after a useful life of tens of years down to as little as only a few years. The results of recent studies by WES (e.g., Lutton, Houston, and Warriner 1981) have stressed the combined importances of rock characteristics and construction and maintenance practices to performance. The variations to be expected of stone materials are particularly critical and will complicate plans for maintenance and repair of these features. It follows that one key ingredient is in control of quality of stone delivered from quarries. However, effective placement and repair procedures are the second important part of construction and these ingredients can sometimes even compensate for the use of marginal stone.

This work unit will be directed toward preparing guidance and criteria on identifying suitable quarry sources by field inspection and sampling, on ensuring delivery of satisfactory stone, and on constructing or repairing for optimum stone packing and stability. Guidance will include that for placement and monitoring in the toe area which can be critical to long-term performance.

Among regions where research can be directly useful are in NCD where dikes and breakwaters have experienced some problems in recent years. The effects of freeze-thaw action will be examined in detail. Improvements are also to be anticipated in NPD and POD where sources, particularly for large jetty stone, are scarce. Other regions are being pressured to use poorer materials by environmental constraints.

The work unit will evaluate the various slope protection materials and develop a matrix relating each type to appropriate conditions for application. Among systems to be evaluated for use in repair are boulders and cobbles, dumped graded stone, quarry run stone, and placed stone. Selection criteria will incorporate cost, performance, and expected life.

Levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	100	100	100			300

Task B: Evaluation of Rock Features

Work Unit 1: Geophysical Techniques for Assessment of Existing Structural Foundations

In many older structures, the condition of foundation materials is problematical either because of a need for safety evaluation by modern methods or because of a need to assess possible deterioration. Problems in some older structures have been caused by solution, piping, or erosion, occasionally with visible loss of ground and the development of sinkholes. In many instances the foundation materials are inaccessible for conventional testing or observation methods. Geophysical methods of evaluation are needed to provide economical and nondestructive determinations of foundation safety conditions.

Geophysical tests of behavior such as P- and S-wave propagation velocity, seismic signatures, and electrical resistivity will provide the means of evaluating foundation conditions, such as density and stiffness, or the presence and extent of voids. Methods will be developed to make systematic and economical surveys in areas of inaccessibility or areas adjacent to concrete or other structures. Tasks will include development of necessary hardware, methodology, and correlations of geophysical properties with foundation conditions of concern.

User products will be a systematic methodology, input to EM's, input to training courses, hardware plans, and specifications.

Levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	100	200	200			500

Work Unit 2: Methodologies for Evaluating Remedial Seepage Control Measures

The use of seepage control measures and the evaluation of various seepage cutoff alternatives are vital aspects of foundation repair and maintenance. The efficiency and cost-effectiveness of control measures are contingent upon not only the location of underseepage or leakage, but also the flow mechanics of the system. Recent studies in the area of fluid flow through fractured rock masses have indicated the need for considering fracture permeability as well as equivalent porous permeability in control of seepage.

Leakage and underseepage have been concerns on numerous Corps projects; recent examples include Gathright, Walter F. George, Wolf Creek, and Hartwell Dams. These occurrences indicate the need for standard methodologies for evaluating remedial seepage control measures in both porous and fractured media. The development of improved test equipment, procedures, and instrumentation has provided the capability for more fully describing the permeability tensor in dam foundations and abutments, and thus a means for planning seepage control measures and evaluating seepage cutoff alternatives.

Methods for planning remedial seepage control have generally been based upon the flow characteristics of porous media or an equivalent porous continuum. The control of flow through fractures in relatively nonporous rock masses will be a primary task of this work unit.

Improved techniques for developing emergency or remedial seepage control grout curtains or diaphragm walls will be developed. Procedures will be tested in the laboratory and in situ if sites are available at operating structures.

Interfacing will be maintained with studies on the use of grout as a foundation mechanical repair method and the development of survey methods to locate grout in situ. Field validation will also be interfaced with studies involving the location and monitoring of underseepage.

Levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	150	150	100			400

Work Unit 3: Rock Erosion
in Spillway Channels

Erosion problems exist at many Corps structures and facilities in the unconsolidated material and the indurated or semi-indurated materials. For example, water from a low-use spillway could be discharging across a hard calcareous shale layer that under most conditions would be fairly erosion-resistant. Slight variations in water chemistry could cause geochemical alterations that would cause the rock to exfoliate and erode rather rapidly. Similar types of erosion problems involve the undermining of lock walls and riprap sections, erosion and navigation hazards downstream of control structures, recreation areas, channel bank and bottoms, foundation problems under or near structures, and sinkhole development in limestone. LMVD and the Fort Worth District in SWD has especially expressed the need for better methods to detect and predict erosion of rock in channels and spillways; the problem is prevalent in many other areas.

The objectives of this study are to: (1) document procedures for detecting and predicting the rate and extent of erodibility of rock spillway channels resulting from physical and chemical processes; (b) identify preventive measures to retard erosion; and (c) present these above procedures in a technical guidance manual for use by Division/District personnel. A survey of existing or potential problem sites within the Corps would be conducted to determine types of rock, hydraulic conditions, and erosive conditions involved. A combination of laboratory and field studies will define cause, effect, and susceptibility of erosion processes on the rocks. Close coordination will be maintained with users in CE offices experiencing erosional problems and with those facing potential problems. Liaison will also be maintained between investigators in the Geotechnical Laboratory study and investigators in a complementary study dealing with spillway scour being conducted by the Hydraulics Laboratory. A large portion of the geotechnical study will address the geochemical aspects of microscopic and macroscopic rock deterioration. Portions of the study involving the physical movements of rock fragments by water will be coordinated closely with the Hydraulics Laboratory

study. Guidance on detecting, predicting, and treatment application and on products and methods will be presented in an EM.

The levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	150	150	100			400

Work Unit 4: Location and Long-Term Monitoring of Subsurface Water Movement

The movement of subsurface water through soil and rock media is a vital concern in the prevention of excessive water losses and piping in dam and foundation materials. There is an acute need for accurate and cost-effective methods to locate and monitor groundwater movements. Recent advances in the state of the art have been promising, and further development could provide the necessary capability.

Problems involving through or underseepage at Corps projects have been numerous; recent examples include Wolf Creek, Gathright, and Clearwater Dams. These occurrences illustrate the widespread need for rapid and accurate evaluations of the groundwater flow regime. The development of improved remote sensing methods for locating and monitoring subsurface water movements could provide early warning of progressively developing hazardous conditions. A state-of-the-art evaluation of location and monitoring methods will be accomplished using a CRREL computer simulation model and field validation tests. First consideration will be given to traditional methods such as monitoring wells, dye tracers, borehole flowmeters, pump testing, and the like. Special attention will be focused on recent developments in flow detection using the self-potential and resistivity geophysical methods. The objective is to develop an advanced and integrated technique for evaluating groundwater movements in soil or rock media.

User products will include input to training courses, input to EM's, and site demonstrations (project-funded).

The levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
			100	100	100	300

Work Unit 5: Short-Term
Weathering and Degradation
of Rock Foundations and Slopes

Rock foundations and slopes occasionally experience an improvement of durability and strength with age as in the so-called "case hardening" phenomenon. Conversely, and of more importance to the maintenance of existing structures, rock rich in clay often experience deterioration with aging. Clay-rich sedimentary rocks in foundations and in compacted embankments can soften and become weaker. Rock exposed in spillway and tailrace slopes and channel surfaces can also deteriorate with time, and at several projects, expansive and periodic remedial measures are required. Detailed understanding of both improvement and deterioration with aging are important in the evaluation, maintenance, and repair of older structures.

The research outlined below would apply particularly to older embankments of clay-rich rock and locks and dams founded on these materials. The results would improve evaluation of stability and pinpoint critical zones for maintenance or repair. The potential loss of anchor support in expansive shales (e.g., Oahe Dam spillway) could be better assessed. This work unit will investigate the physical and chemical processes involved in short-term weathering, particularly for rocks. Cases experienced by the Corps will be reviewed in order to develop criteria for predicting aging and the consequences to structures constructed of weatherable materials. Among important questions to be answered is "To what depth does the phenomenon penetrate--as in a rockfill embankment, for example?"

Data on depth of deterioration and softening of susceptible rock in embankments and beneath structures and on depth of weathering in rock spillway cuts will be developed. Criteria for recognizing problem materials and assessing critical locations in an embankment, channel, or foundation also will be developed.

Levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
			100	150	150	400

Work Unit 6: Selection and
Inspection of Rock Reinforcement

Rock reinforcement can be used to arrest damage in distressed foundations, slopes, and tunnels. The design of rock reinforcement as a remedial measure requires an understanding of both the cause of the distress and the role of the reinforcement in halting further deterioration.

This work unit will develop a design methodology to evaluate distress in rock and to design rock reinforcement systems to halt further damage. Types of damage and distress in rock will be identified, and a classification scheme will be proposed. The classification scheme will be used to indicate the types of rock reinforcement that can halt further damage. Cases where rock reinforcement has been used to limit distress will be evaluated to examine the effectiveness of the rock reinforcement.

A methodology will be developed that will aid in identification of types of damage in rock and will suggest measures that may be effective in arresting further damage. A method for evaluating the effectiveness of existing rock reinforcement and for inspecting the rock and small-diameter rockbolt holes will be developed.

Levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
				200	200	400

Work Unit 7: Evaluation of Current
Sliding Stability and Deformation
Criteria with Respect to the
Performance of Aging Foundations

The Corps recently changed the criteria for evaluating the sliding stability of gravity structures. Previous criteria were based on the shear-friction method developed in the mid-1930's. Current criteria are based on the limit equilibrium method. Recent reevaluations of several aging structures have indicated that some of these structures do not

meet the current design criteria. However, these structures have shown no sign of instability. The Federal Lock and Dam at Troy, N. Y., is one such example.

The current sliding stability design criteria are based on sound and reliable geotechnical engineering principles. The fact that some aging but stable structures do not meet current criteria does not reflect poor prediction capabilities of the criteria, but rather reflects the inability to predict realistic prototype shear strength parameters. Poor shear strength predictions can be primarily attributed to the inaccessibility of foundation conditions. Because foundation conditions are not known with a high degree of confidence, overly conservative shear strengths are often selected for reevaluation purposes.

The shear strength of rock foundations is controlled by discontinuities. Current state-of-the-art procedures are available for determining upper and lower boundaries of expected shear strength for discontinuous rock. Such procedures require as a minimum high-quality, small-diameter core specimens.

This work unit can best be addressed in two phases:

a. Phase I. Because upper- and lower-bound shear strength determinations are dependent upon high-quality, small-diameter core specimens, minimum guidance must be established for obtaining suitable specimens. Various integral sampling techniques will be evaluated for this purpose.

. Phase II. Upper- and lower-bound strengths provide a measure of the range of potential scale effects contributing to prototype strengths.

Past performance of structures and construction records pertaining to actual foundation conditions will be used as a basis for adjusting boundary strengths to reflect more realistic prototype strengths. Foundation deformation is a key indicator of stability. Structures that have undergone little or no movement are assumed to be performing well. Structures that have undergone substantial movements often show distress as cracking or misalignment of structural elements. Concurrent with the investigation of strength, the foundation deformation will be verified. The relationship between strength and deformation will be examined. Measured displacements may be influenced by the type of structure and

its service loadings. When a structure is investigated, the movement will be recorded by type; i.e., sliding, rotation, settlement. Evaluation of such records for a number of structures will establish typical levels of movement that can be used to refine prediction of movements made during design. The movement information can be used to evaluate the effectiveness of remedial anchor systems in restraining movement. The results of this work unit will provide a rational means of selecting realistic prototype strengths for existing structures founded on discontinuous rock foundations and will permit prediction of foundation deformations.

Levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
				250	250	500

Table CIV-1

Summary of Funding Levels

Rock Research Subarea

Work Unit	Funding for Cited Fiscal Year, $1000's 84	85	86	87	88	89	Total
Task A: Repair of Rock Features							
1. Grouting Practices for Repair and Rehabilitation of Rock Foundations	100	150	150				400
2. Determination of In Situ Grout Distribution in Structural Foundations		125	125	150			400
3. Repair Practices and Quality Control for Rock Slope Protection		100	100	100			300
Task Totals	100	375	375	250			1100
Task B: Evaluation of Rock Features							
1. Geophysical Techniques for Assessment of Existing Structural Foundations		100	200	200			500
2. Methodologies for Evaluating Remedial Seepage Control Measures		150	150	100			400
3. Rock Erosion in Spillway Channels		150	150	100			400
4. Location and Long-Term Monitoring of Subsurface Water Movement				100	100	100	300
5. Short-Term Weathering and Degradation of Rock Foundations and Slopes				100	150	150	400
6. Selection and Inspection of Rock Reinforcement					200	200	400
7. Evaluation of Current Sliding Stability and Deformation Criteria With Respect to the Performance of Aging Foundations					250	250	500
Task Totals		400	500	600	700	700	2900
Subarea Totals	100	775	875	850	700	700	4000

PART V: HYDRAULICS

Scope of Research

The research discussed below addresses the problems identified in Section B, PART V. Accomplishment of this research will provide a sound basis for developing REMR methods for hydraulic aspects of Corps projects. Such efforts will, in turn, serve to enhance and prolong the life of these projects.

The work units in this research area are as follows:

Flood Control Subarea:

Work Unit 1. High-Level Emergency Spillway Scour

Work Unit 2. Scour Downstream from Stilling Basins

Work Unit 3. Predictive Techniques for Approach Flow Conditions to Spillways and Other Structures

Work Unit 4. Floating Debris Control Systems

Navigation Subarea:

Work Unit 1. Evaluation of Channel Reaches with High Accident Rates

Work Unit 2. Lock Gate Impact Barriers

Work Unit 3. Scour Detection and Repair Around Navigation Training Structures

Work Unit 4. Techniques for Repair of Training Structures

Table CV-1 at the end of this part summarizes the funding levels required to accomplish the research needed in the Flood Control and Navigation subareas.

Flood Control Subarea

Work Unit 1: High-Level Emergency Spillway Scour

The objective of this work unit is to evaluate the causes of severe and excessive scour downstream of emergency spillways that do not have energy dissipators and to develop better guidance for repair and rehabilitation of reaches between the emergency spillway and a downstream

reach of quasi-stable exit channel or river. During the first year, a test flume will be designed and constructed. Laboratory tests and associated data analyses will be conducted during the second and third years. Prototype spillways such as Grapevine and Lewisville in SWD will be modeled to evaluate and verify causes of erosion and alternative solutions. Parameters which identify the potential for severe scour will be developed to permit identification of existing Corps emergency spillways that are likely to experience scour problems. Certain operational modifications will be studied in addition to the general structural solutions, and recommendations for changes will be made where appropriate.

The knowledge gained from the study will be incorporated into REMR sections of existing manuals or in ETL's. Application of the research results can prevent the occurrence of severe scour, structural damage and provide the best repair or rehabilitation approach for emergency spillways already endangered or with a potential for severe scour.

Levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
110	160	150				420

Work Unit 2: Scour Downstream from Stilling Basins

Numerous older hydraulic structures have experienced excessive scour downstream from the stilling basin. Repair efforts are generally based on previous experience, if any, or model studies of specific projects. Research is needed to develop better guidance for repair and rehabilitation of scoured areas. Data from past hydraulic model studies will be analyzed, and a survey and evaluation of methods of protection used by various Corps Districts will be made. Some of the more promising methods of protection and types of protective materials will be tested in a physical model to develop rehabilitation criteria and techniques needed to control scour and reduce costly repair and maintenance at existing hydraulic structures. Information gained from the study will be transferred to the field through technical reports, training courses, and EM's.

Levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	140	150	150	60		500

Work Unit 3: Predictive Techniques for Approach Flow Conditions to Spillways and Other Structures

The research will result in the development of a hybrid modeling capability. During the first year, the most appropriate candidate numerical models available will be selected, set up, and executed for a test case where laboratory and/or field data exist. During the second year, the best candidate numerical hydrodynamic model will be identified as well as the improvements that need to be made. During the third and fourth years, a numerical hydrodynamic model will be developed to allow rapid evaluation of the numerous alternative spillway modifications and flow conditions and expedite determination of the need for and the selection of candidate modifications prior to simulation in physical models. This capability will result in consideration and evaluation of more alternatives and will reduce the time and cost required for development while ultimately leading to higher quality corrective actions. It is anticipated that the cost of developing a satisfactory spillway modification will be reduced by a fourth to a third.

Levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	50	100	150	150	50	500

Work Unit 4: Floating Debris Control Systems

A line of floating timbers, single or built-up, is the presently used containment device for floating debris including ice. Floating debris is an expensive nuisance and at times a severe problem. More functional structures and arrangements should be developed to effectively

collect and remove debris at appropriate locations upstream and downstream of structures where it is convenient and to make the problem more manageable.

During the first year of research, a review of Corps Districts' problems and solution methods will be made to initiate development of improved debris collection and removal. Efforts during the second year will center on development of practical methods of managing debris including conduct of both laboratory tests and field observation of selected recommended methods. The effort will be completed during the third year. Benefits derived from this work will include increased safety, lower maintenance cost by virtue of less scour and structural repair, less interference with navigation and power generation, and more effective flood control operation.

Levels of funding are as follows ($1000'):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	150	150	150			450

Navigation Subarea

Work Unit 1: Evaluation of Channel Reaches with High Accident Rates

The objective of this element is to improve the safety of operations and reduce repair and maintenance costs by reducing rammings and groundings in those waterway reaches with clusters of accidents, about thirty-five 10-mile segments. The methods for accomplishing this include realignment of the channel approaches to structures, channel widening or deepening, relocation of structures, realignment of currents, provision of wind protection, and provision of additional navigation aids and information. The first year's work will involve in-depth review of accident reports, statistics and analysis reports of these, selection of reaches for further analysis based on accident causes and potential for improvement of operating conditions, and gathering required data and information on those selected reaches. Based on the problems indicated in

the accident analysis, model studies will be designed in the following years to further identify probable causes and potential rehabilitation schemes that can improve the operational safety of each reach. Model studies will include mathematical and physical models, tow simulator studies, and field measurements as necessary. This approach will allow full evaluation of physical forces and navigator perception, evaluation, and response to each situation. Potential rehabilitation actions can then be evaluated by the field offices. The final year will involve preparation of a report evaluating the navigation problems identified and the solutions developed and preparation of a report and REMR section for existing manuals, as appropriate, describing these for use in similar cases. Application of the research results can be used to prevent similar problems from developing in the future through better design criteria.

Levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	150	150	150	100		550

Work Unit 2:
Lock Gate Impact Barriers

Research is needed to develop effective methods of protecting miter gates from vessels with a minimum sacrifice of lock chamber length. A physical model of a lock approach and the lock chamber with gates will be used for the study. A free-running and man-on-board-operated vessel will be used to investigate forces involved and various methods for protecting the gates such as cables, nets, etc.

Monetary benefits from this research would be the savings of costs to repair gates after accidents and loss of the navigation system to shipping interests while these repairs are being made as stated in Part V, Section B. Also, the research will result in safer operating conditions at locks.

Information gained from the research will be transferred to the field through technical reports, training courses, and EM's.

Levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	100	200	200	200	100	800

Work Unit 3: Scour
Detection and Repair Around
Navigation Training Structures

The objective of this work unit is to develop methods for detecting and repairing scour near the base of training structures prior to incurring major damage to the structure during episodic storm events. The approach proposed for this work includes identification and field evaluation of bottom-imaging devices such as side-scan sonar (year 1), development of damage criteria, and identification and field evaluation of repair methods for scour damage (years 2, 3, and 4). Benefits to be derived from this work include lower maintenance costs by virtue of being able to identify and repair scour damage in its early stages, and increased integrity and reliability of structures due to their ability to withstand greater hydrodynamic and scouring forces. Information developed by this work will be disseminated through technical reports, ETL's, and addendum to existing or input to new EM's.

Levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	150	150	150	150		600

Work Unit 4: Techniques for
Repair of Training Structures

The objective of this work unit is to document present Corps practices concerning repair or rehabilitation of estuarine and riverine deep- and shallow-draft training structures. At present, the repair of revetments and dikes is based on experience usually within a particular Corps District with no general guidance available for the evaluation and planning for repair of these type structures. This work unit will cover the anticipated life of training structures; the evaluation of when

the effectiveness of the structures is decreased to a point that repair or rehabilitation is necessary; the cost of repair versus replacement; the effects of conditions such as ice, flood flows, and navigation; and the planning procedure for repairing.

The deep-draft training structure program will begin in FY 85 with the initial year used for project identification and limited data collection. A deep-draft training structure symposium will be held at WES with Corps personnel who perform the planning and design of repair work on dike fields and revetments. This will be an excellent way of making contacts and exchanging information early in the research program within the Corps community. FY's 86 and 87 will be used for completing prototype data collection and the analysis of that data. FY 88 will be used for report writing and adding a REMR section to existing deep-draft EM's.

The shallow-draft training structures program will also begin in FY 87 with the first year being used mainly for data collection. A shallow-draft symposium will be held at WES with Corps personnel who actually perform the planning and design for repair work on dikes and revetments. FY 88 will be used for completion of the accumulation of prototype data and analysis of that data. FY 89 will be used for report writing and preparation of results for inclusion in a REMR section of existing EM's.

Levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	100	100	200	200	100	700

Table CV-1

Summary of Funding Levels

Hydraulics Research Area

Work Unit	Funding for Cited Fiscal Year, $1000's						
	84	85	86	87	88	89	Total
Flood Control Subarea							
1. High-Level Emergency Spillway Scour	110	160	150				420
2. Scour Downstream from Stilling Basins		140	150	150	60		500
3. Predictive Techniques for Approach Flow Conditions to Spillways and Other Structures		50	100	150	150	50	500
4. Floating Debris Control Systems		150	150	150			450
Subarea Totals	110	500	550	450	210	50	1870
Navigation Subarea							
1. Evaluation of Channel Reaches with High Accident Rates		150	150	150	100		550
2. Lock Gate Impact Barriers		100	200	200	200	100	800
3. Scour Detection and Repair Around Navigation Training Structures		150	150	150	150		600
4. Techniques for Repair of Training Structures		100	100	200	200	100	700
Subarea Totals		500	600	700	650	200	2650
Area Totals	110	1000	1150	1150	860	250	4520

PART VI: COASTAL

Scope of Research

The tasks and work units in this research area are as follows:

Task A: Coastal Structures

- Work Unit 1. Rehabilitation of Rubble-Mound Structure Toes
- Work Unit 2. Techniques of Reducing Wave Runup and Overtopping on Coastal Structures
- Work Unit 3. Repair of Localized Damage to Rubble-Mound Structures
- Work Unit 4. Use of Dissimilar Armor for Repair and Rehabilitation of Rubble-Mound Coastal Structures
- Work Unit 5. Evaluation of Damage to Underwater Portions of Coastal Structures
- Work Unit 6. Experimental Testing of Methods for Reducing Wave Runup and Overtopping on Coastal Structures
- Work Unit 7. Experimental Testing of Methods and Materials for Repair of Localized Damage to Rubble-Mound Structures

Task B: Harbor Entrances and Coastal Channels

- Work Unit 1. Development of Methods and Techniques for Minimizing Maintenance Requirements of Coastal Navigation Channels

Task C: Shore Protection and Restoration

- Work Unit 1. Improved Techniques for Post-Storm Inspection and Evaluation

Table CVI-1 at the end of this part summarizes the funding levels to accomplish the research.

Task A: Coastal Structures

Work Unit 1: Rehabilitation of Rubble-Mound Structure Toes

Many failures of rubble-mound navigation and shore protection structures can be traced to the collapse or movement of the material

comprising the toe of the structure. Such failures, usually caused by construction deficiencies or underestimation of waves and currents at the site of the structure, lead to instability of the armor layers, allowing the cores of the structures to be directly exposed to erosive forces. The objective of this work unit will be to determine the exact causes of documented structural failures and to conduct experimental tests to develop improved methods for the rehabilitation of rubble-mound toes and particularly methods for integrating the bedding layers and toe protection into the structure itself. Results of the study will be made available to field offices in the most expeditious manner (ETL's and workshops) and incorporated in appropriate manuals. This information will provide guidance on reliable and successful methods for rehabilitating the toe areas of rubble-mound structures and will minimize future expenditures for such repairs.

Levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
50	200	300	300	250		1100

Work Unit 2: Techniques of Reducing Wave Runup and Overtopping on Coastal Structures

There are known cases where existing coastal structures have been damaged by excessive wave runup and overtopping, particularly dikes constructed in open waters for containment of dredged material. It is proposed to conduct an exhaustive survey of the Districts/Divisions to determine if runup and overtopping are, in reality, a problem and if so to quantify the magnitude (in terms of dollars) of the problem. Should the results of this survey warrant additional investigations, work will be undertaken in Work Unit 6 of this task to determine methods and techniques suitable for rehabilitation of structures in order that damage will be reduced or eliminated. CRREL will actively participate in this work unit to ensure complete consideration of ice effects on runup and overtopping. Knowledge developed from this work will be made available to the field offices by means of workshops and appropriate ETL's and EM's.

Levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	100	100				200

Work Unit 3: Repair of Localized
Damage to Rubble-Mound Structures

The purpose of this work unit is to provide effective and long-lasting means and materials for the repair of small but critical areas of breakwater damage. Due to the introduction of new types of armor, it is essential that the field be provided reliable guidance on optimal methods for repair of localized damage. Many times, the existing structure cannot effectively be repaired with like armor, yet there is no guidance on how to repair with other materials. The shape, location, etc., of the physical damage are often critical, and access is often limited. Field experiences will be studied, and the relative merits of both successful and unsuccessful techniques will be reported and distributed. The dollar magnitude of this problem to the Corps also will be quantified. If this problem is documented to be of sufficient magnitude to warrant additional investigations to develop suitable repair techniques, these studies will be conducted under Work Unit 7. Active study participation by CRREL will ensure that ice damage and subsequent repair techniques are fully considered. Results of the study will be reported in appropriate ETL's, EM updates, or special reports on "how" and "how not to" repair localized damage. Benefits from this work unit will result in better repairs, thereby minimizing future maintenance costs.

Levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	100	100				200

Work Unit 4: Use of Dissimilar
Armor for Repair and Rehabilitation
of Rubble-Mound Coastal Structures

Several Corps coastal projects where rubble-mound structures were rehabilitated and/or repaired with armor units of larger or dissimilar types have revealed a total lack of guidance or even information concerning the interactions of armor units of various sizes or dissimilar types. Definitive information will be collected on those projects where such work has been undertaken. Experimental breakwater stability tests (of sufficient size to preclude laboratory scale effects) will be conducted. These tests will develop data quantifying the best alternatives for the rehabilitation of rubble-mound structures where it is impractical or economically unjustified to use armor units of similar size or shape to those of the existing structure. These data will be used to provide information and guidance on reliable methods for repairing and rehabilitating this type of structure. Cost-effective and functional methods of repair and rehabilitation will be developed. Results of the investigation will be made available to the field offices by means of special reports and workshops and incorporated into appropriate EM's and ETL's.

Levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	150	150	100	150		550

Work Unit 5: Evaluation of
Damage to Underwater Portions
of Coastal Structures

Coastal structures suffer damage due to storms that often cannot be detected because the damage lies below the water surface. This work unit proposes to develop methods for accurately delineating the extent of such damage, particularly damage occurring at or near the toe of a structure. Various methods of underwater detection and surveying will be examined, evaluating the potential of the methods and devices for accurately measuring such damage. A system or systems will be selected for field testing, and specific procedures for its (their) use will be

developed for rapid determination of the underwater structural integrity of coastal structures. Such a system(s) will allow systematic surveys to evaluate damage to underwater portions of coastal structures and enable repairs to be undertaken before catastrophic events produce extensive damage to or destroy the structure. Results of this study will be presented to field offices via appropriate Corps manuals and onsite workshops for field personnel.

Levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	150	150	200	200	50	750

Work Unit 6: Experimental Testing of Methods for Reducing Wave Runup and Overtopping on Coastal Structures

Should the results of Work Unit 2 above warrant additional investigations to develop specific methods for reducing wave runup and overtopping of rubble-mound coastal structures, laboratory investigations of those methods and techniques will be undertaken. These tests will be used to determine the relative merits of different alternatives for reducing runup and overtopping of coastal structures (such as crown-mounted and/or toe tripping types of structures) to determine functional methods for their construction. Results of these tests will be made available to the field office by means of ETL's and incorporating data into appropriate EM's.

Levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
			100	150	100	350

Work Unit 7: Experimental Testing of Methods and Materials for Repair of Localized Damage to Rubble-Mound Structures

Information developed in Work Unit 3 above will relate field experiences with the methods and techniques of repairing localized damage

to rubble-mound structures; however, experimental investigations will be conducted to determine the best methods and techniques for meshing of different types of armor protection in a localized area. Such tests will result in definitive information that will allow field engineers to select the proper type and size of armor to be used in repairing localized damage and the best methods for placing the new armor material to ensure the stability of the structure. Results will be furnished as specific reports and ETL's and will be incorporated into appropriate EM's.

Levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
			100	150	100	350

Task B: Harbor Entrances and Coastal Channels

Work Unit 1: Development of Advanced Methods and Techniques for Evaluating and Minimizing Maintenance Requirements of Coastal Navigation Channels

In order that coastal navigation channel maintenance projects be managed in the interest of economic efficiency and environmental quality, there is an urgent need for a comprehensive quantitative understanding and evaluation of all phases of the movement of maintenance material in the presence of waves. The objective of this study is to better understand:

a. Movement of bottom material within coastal navigation channels and adjacent waters in the presence of waves and wind-driven and/or tidal currents.

b. Movement of maintenance material at disposal sites in the presence of waves and wind-driven and/or tidal currents.

c. Response of various bottom sediments to coastal hydrodynamic forces under varying chemical and biological conditions.

The approach is to combine the latest advancements in mathematical modeling, laboratory investigations, field measurements, and remote sensing to build up a comprehensive predictive model for determining the dynamic response of maintenance material to the wind, wave and tidal, etc., forcing functions. Advances such as those achieved in recent numerical

modeling efforts and comprehensive field data acquisition using state-of-the-art remote sensing devices such as the AOL (Airborne Oceanographic LIDAR (Light Detecting and Ranging), a laser instrument for measurement of waterborne sediments and bathymetry) will be used to develop a sound regional plan of maintenance alternatives, not only for the short-term, but more importantly for the long-term (considering potential subsequent resuspension and transport of maintenance material due to combined wave and current actions). Currently used numerical models for evaluating such problems have dramatic and intolerable technical deficiencies. Models currently in use neglect the radiation stress terms caused by wave-induced mass transport. These radiation stress terms cause a significant modification to the current profile which in turn affects the transport and deposition of sediments. The approach envisioned will eliminate these deficiencies and enable the reliable use of numerical models in the presence of waves (and currents).

Specific efforts required to accomplish these objectives are:

a. Incorporation of an optimal numerical grid generation scheme into an existing three-dimensional, finite difference hydrodynamic model to better represent the complex shoreline and channel geometries and bottom topography.

b. Modification of the model to better represent the larger vertical velocities in areas of abrupt bathymetric variation.

c. Critical review and assessment of the state of the art of models for estimating the short-term dynamic response of maintenance material.

d. A study of the turbulent bottom boundary layer under combined current-wave interaction using one- and two-dimensional turbulence models.

e. Incorporation of results from these turbulent modeling studies to improve the turbulence parameterization in the hydrodynamic, wave, and sediment dispersion models.

f. Development of a Lagrangian sediment dispersion model to better represent the time history of the movement of maintenance material.

g. Design and conduct of critical field measurement programs for model calibration and verification.

h. Comprehensive laboratory studies of the response of sediments to hydrodynamic forces under varying chemical and biological conditions.

Products from this study will significantly enhance our quantitative understanding of the dynamic response of maintenance material and will result in:

a. The ability to reliably evaluate and minimize future maintenance requirements for coastal navigation channels.

b. Economically and environmentally sound regional plans for the maintenance of coastal navigation channels.

c. Better quantitative assessment of potential maintenance impacts on coastal regions.

d. Definitive prediction of the long-term fate of maintenance material which will lead to savings by minimizing legal disputes with local communities and various advocacy groups challenging Corps maintenance operations for coastal navigation channels.

Levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
50	200	200	200	200	50	900

Task C: Shore Protection and Restoration

Work Unit 1: Improved Techniques for Post-Storm Inspection and Evaluation

Storms cause almost all significant coastal erosion, and beaches and offshore areas begin to accrete and recover from storm erosion very soon after passage of the storm. Our ability to quantify storm erosion effects is seriously limited by our inability to rapidly and accurately measure nearshore bathymetry and topography. Novel and innovative techniques for making post-storm inspections need to be developed. Remote sensing techniques may offer the most promise of accomplishing this objective. The objective of this study is to evaluate those remote sensing techniques and instruments which are presently available or are being developed to rapidly measure bathymetry under adverse weather conditions, such as the AOL and satellite systems (e.g., the Thermatic mapper aboard LANDSAT "D").

Levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	100	100	100			300

Table CVI-1

Summary of Funding Levels

Coastal Research Area

Work Unit	Funding for Cited Fiscal Year, $1000's 84	85	86	87	88	89	Total
Task A: Coastal Structures							
1. Rehabilitation of Rubble-Mound Structure Toes	50	200	300	300	250		1100
2. Techniques of Reducing Wave Runup and Overtopping on Coastal Structures		100	100				200
3. Repair of Localized Damage to Rubble-Mound Structures		100	100				200
4. Use of Dissimilar Armor for Repair and Rehabilitation of Rubble-Mound Coastal Structures		150	150	100	150		550
5. Evaluation of Damage to Underwater Portions of Coastal Structures		150	150	200	200	50	750
6. Experimental Testing of Methods for Reducing Wave Runup and Overtopping on Coastal Structures				100	150	100	350
7. Experimental Testing of Methods and Materials for Repair of Localized Damage to Rubble-Mound Structures				100	150	100	350
Task Totals	50	700	800	800	900	250	3500
Task B: Harbor Entrances and Coastal Channels							
1. Development of Methods and Techniques for Minimizing Maintenance Requirements of Coastal Navigation Channels	50	200	200	200	200	50	900
Task Totals	50	200	200	200	200	50	900
Task C: Shore Protection and Restoration							
1. Improved Techniques for Post-Storm Inspection and Evaluation		100	100	100			300
Task Totals		100	100	100			300
Area Totals	100	1000	1100	1100	1100	300	4700

PART VII: ELECTRICAL AND MECHANICAL

Scope of Research

The tasks and work units in the Electrical and Mechanical research area are as follows:

Task A: Corrosion Mitigation Design

- Work Unit 1. Corrosion-Resistant Materials for Civil Works Structures
- Work Unit 2. Civil Works Corrosion Mitigation and Management System

Task B: Protective Coatings

- Work Unit 1. Painting of Submerged Surfaces
- Work Unit 2. Development of High-Solids Coatings

Task C: Turbine, Generator, and Pumping Station Repairs

- Work Unit 1. Nondestructive Evaluation of Electrical Insulation in Rotating Machinery
- Work Unit 2. Minimization of Cavitation Repair of Turbines

Task D: Miscellaneous Maintenance and Repair of Hydraulic Structures and Equipment

- Work Unit 1. Evaluation of Gate Seals and Gate Seal Heaters
- Work Unit 2. Evaluation of the Use of SF_6 Circuit Breakers
- Work Unit 3. Effectiveness of Cathodic Protection Systems
- Work Unit 4. Use of Synthetic Oils for Exposed Reduction Gears
- Work Unit 5. Energy Management and Control Systems for Corrosion Inhibiting Equipment
- Work Unit 6. Development of Procedures for Using Vibration as a Maintenance Tool
- Work Unit 7. Identification of Basis for O&M Expenditures for Hydraulic Structures
- Work Unit 8. Control of Roosting Birds and Bird Waste
- Work Unit 9. Compatibility of Insulating and Lubricating Oils

Task D: (Continued)

Work Unit 10. Fire Protection at Civil Works Structures

Table CVII-1 at the end of this part summarizes the funding levels for this research area.

Task A: Corrosion Mitigation Design

The objective of this task is to provide increased capability for corrosion mitigation through improved cathodic protection systems (ceramic anodes), material selection, and implementation of a maintenance management system. The use of ceramic anodes will provide less costly, more reliable, and more easily maintained cathodic protection systems. Introduction of corrosion-resistant materials into the specifications will reduce corrosion damage during operation. The implementation of a maintenance management system will lower costs while improving maintenance activities.

Corrosion-related problems can amount to 20% of the yearly maintenance and repair budget at some projects. There are several reasons associated with these high costs. First, it has been found that cathodic protection systems, though effective when operational, are not properly maintained in many instances and thus not operational some of the time. The use of ceramic anodes will result in systems requiring less maintenance and ones that can be replaced without dewatering. Second, many corrosion problems are a result of the design process, where advantage is not taken in specifying corrosion-resistant materials and designs. Third, there is no existing capability for assessing the present condition and the remaining service life of a metal structure. This results in poorly scheduled maintenance and repair activities. A maintenance management system can reduce the impact of this problem considerably.

These studies will utilize the results of previous work. Ceramic anodes have already been developed; all that remains is to refine production methods and conduct field tests. Corrosion-resistant materials will be assessed in the laboratory, followed by field tests. A guide

for designers will be prepared. A maintenance management system will be developed along the lines of a similar system already being developed for military installations.

Work Unit 1: Corrosion-Resistant
Materials for Civil Works Structures

The objective of this work unit is to evaluate new corrosion-resistant materials and develop a material selection guide for corrosion control in Civil Works structures. New corrosion-resistant casting materials will be evaluated in the laboratory and in the field. Laboratory evaluation will include testing of cavitation, pitting corrosion, weldability, and sensitivity to heat treatment. Field testing of parts such as pump casings will be carried out and a selection guide will be developed for use by design engineers. Benefits will be in the form of reduced expenditures because of less frequent replacement of components prone to corrosion.

Funding levels are ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	100	100	50			250

Work Unit 2: Civil Works Corrosion
Mitigation and Management System

The objective of this work unit is to develop techniques to assess and predict the corrosion status of aging metallic Civil Works structures. Technology will be developed to predict the corrosion status of immersed metallic structures (such as lock gates) and buried structures (sheet piling and tiebacks). The technology will be based on the corrosivity of the medium. Various maintenance strategies, with and without cathodic protection, will be evaluated and guidelines provided. Benefits will be improved procedures for assessing the corrosion status of metal structures; lower repair costs; and a practical method for establishing work priorities.

Funding levels are ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
		100	150	100	50	400

Task B: Protective Coatings

The objective of this task is to develop materials and techniques for improving the performance of corrosion-resistant coatings for hydraulic structures. Coating systems are the primary protection used to prevent corrosion of metal structures. Improved materials and techniques will reduce maintenance costs and extend the service life of the structures.

Recent and forthcoming air pollution regulations have required the reformulation of the most successful coating systems used by the Corps to prevent metal structures from corroding. These substitute coatings are not performing as well as the original ones, thus increasing maintenance costs considerably. These same regulations are inhibiting the use of sandblasting, thus requiring more costly paint removing methods to be used in maintenance and repair activities. Other items contributing to higher costs of maintenance include the requirement to dewater before painting and the lack of ability to assess the debonded areas of coal tar epoxy so that spot repairs can be made rather than reducing the entire surface. This research will address these and other problems that, when solved, will result in lower maintenance and repair costs and improved performances.

Work Unit 1: Painting of Submerged Surfaces

The objective of this work unit is to develop coatings and application methods for the application of protective coatings to steel structures which cannot be dewatered. Available proprietary coatings designed for underwater application will be obtained and evaluated. Specialized surface preparation equipment and coating applicators will be evaluated. The most effective equipment and the most durable coatings will be evaluated on Corps hydraulic structures. The ability to apply protective coatings to structures which cannot be dewatered will substantially

extend the service life of the items subjected to corrosion. In other instances, spot repairs performed underwater will eliminate the need for costly dewatering.

Funding levels are ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
		100	50			150

Work Unit 2: Development of High-Solids Coatings

The objective of this work unit is to develop a durable coating system for use on hydraulic structures exposed to immersion in low-velocity, nonabrasive waters. Coatings will be designed for application with airless spray. The complete system will be applied in three spray passes. Formulation work will be performed and proprietary products will be evaluated to determine optimum properties obtainable. High-solids coatings will reduce application costs by at least one-half compared to standard vinyl systems currently being used.

Funding levels are ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
			100	50		150

Task C: Turbine, Generator, and Pumping Station Repairs

The objective of this task is to develop techniques and procedures for determining the existing condition of insulation in generator and motor windings and for predicting the remaining service life and minimizing cavitation damage of hydraulic turbines.

Repairs of hydraulic turbines and generators are very costly, especially as a result of downtime. Much of this is due to turbine blade cavitation and the necessity to rewind generators because of winding insulation breakdown. A need exists for better cavitation repair

techniques and for methods of determining the present conditions of the generator winding insulation and the remaining service life. More realistic maintenance activities would result.

For cavitation repairs, several candidate systems will be laboratory tested, and those with the greatest potential would then be tested in the field. For generator windings, the Doble test will be studied for possible adaption, and the phenomenon associated with the change of the complex impedance of the windings will be investigated. The final system will be tested on an in-place generator.

Work *Unit 1: Nondestructive* Evaluation of Electrical Insulation in Rotating Machinery

The objective of this work unit is to develop techniques and procedures for determining the existing condition of insulation in generator and motor windings, and for predicting the remaining service life. High-potential AC and DC testing of insulation is the most widely used technique for evaluating electrical winding insulation, but this method is highly controversial and can be destructive. In addition, the results are difficult to interpret and the remaining service life is still difficult to determine. Several approaches are contemplated: (a) utilization of the phenomenon associated with change of the complex impedance of the windings, and (b) the Doble test, which is a method that provides for a measurement of the power factor over a period of time, and relates the change to an estimated *time for failure to occur.* Candidate systems will be first tested in the laboratory and then on field installations. Techniques will be developed for predicting the remaining service life of the insulation. Criteria and guidance for use will be prepared. The potential for huge cost savings exists. Generators will not be rewound prior to need, and the danger of a complete failure, with the attendant loss of use for an extended period, will be greatly reduced.

Funding levels are ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	100	100				200

Work Unit 2: Minimization of
Cavitation Repair of Turbines

The objective of this work unit is to reduce the amount of cavitation damage that occurs on hydraulic turbines. This effort will consist of the following steps: (a) determination of the extent of cavitation repair at existing projects; (b) selection of one or two projects on which the unit will be repaired to a smooth finish with no hollows or high spots; (c) selection of a second unit in the same powerhouse to be given the normal amount of cavitation repair which will provide a base for determining the effect of the work; (d) operation of both units in a similar manner for the test period (i.e., same head, hours of operation, power output, and tailwater elevation); and (e) evaluation of the units at the end of the test period to determine the difference in cavitation damage. Benefits will be lower maintenance costs for cavitation repair of turbines and reduced downtime and subsequent loss of power generation.

Funding levels are ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
			100	80	40	220

Task D: Miscellaneous Maintenance and Repair
of Hydraulic Structures and Equipment

The objective of this task is to investigate the reasons for poor performance of components of hydraulic structures that result in high maintenance costs and energy consumption and costly downtime. The studies will result in improved performance of the structures, with lower maintenance and repair costs and reduced downtime.

There are many small equipment problems associated with the operations of hydraulic structures that do not warrant large-scale studies; however, their impact on the performance of the various components of which they are a part is great. The results are higher than average maintenance and repair costs than would ordinarily be expected. These problems include failure of: gate seals and gate seal heaters; circuit breakers at pump storage plants; cathodic protection systems; oil heaters

in gear reduction boxes; tainter gate hoisting equipment; lock gate operating machinery; and corrosion inhibiting equipment. Other problems related to health and safety to be addressed include guidance for fire protection at Civil Works structures and control of roosting birds and bird waste. High energy consumption of high-voltage AC and the difficulty of predicting equipment failure and maintenance needs also require investigation. All of these will be included in this study.

Utilization will be made of existing applicable materials, techniques, and procedures both within the Corps and in private industry. Development of new solutions will only be undertaken as required. The general procedure will be to conduct laboratory studies to first determine those items with the greatest potential for solution. These will then be field tested as required.

Work Unit 1: Evaluation of
Gate Seals and Gate Seal Heaters

The objective of this work unit is to determine causes of failures of gate seals and gate seal heaters in large hydraulic structures, and to develop guidance to minimize frequency of replacement. Actual field gate seal and heater failures will be evaluated from both the design and operations aspects. Reasons for the failures will be determined and documented. Recommended design and installation procedures will be developed and field tested. The information will be disseminated through an EM. This study will result in improved operational capability, reduced maintenance costs, and the avoidance of long out-of-service periods.

Levels of funding are ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	40	90				130

Work Unit 2: Evaluation of
the Use of SF_6 Circuit Breakers

The objective of this work unit is to evaluate the use of SF_6 circuit breakers at a pump storage hydropower plant. Pump turbines require operation of circuit breakers while carrying very large electrical

currents. This operation greatly reduces the life of the circuit breakers and results in high maintenance costs. SF_6 circuit breakers have been proposed for use at Carter's Powerhouse. This work unit would monitor the cost and reliability of the SF_6 circuit breakers.

Levels of funding are ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	50	50				100

Work Unit 3: Effectiveness
of Cathodic Protection Systems

The objective of this work unit is to determine the effectiveness of in-place cathodic protection systems as presently maintained and operated. Several installations of each type of cathodic protection system presently being used by the Corps will be evaluated in place. These will include the button, sausage, and platinized anode systems. The evaluation will include: type of system; age; initial cost; maintenance requirements and costs; periods of nonuse; and perceived effectiveness. The evaluation will be presented in a report, with recommended guidelines for improving the effectiveness of such systems. This research is expected to provide guidance that will result in more effective use of cathodic protection systems and thus reduce maintenance and replacement costs of structures as a result of corrosion.

Funding levels are ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total

(included in Task B)

Work Unit 4: Use of Synthetic
Oils for Exposed Reduction Gears

The objective of this work unit is to determine the effectiveness of synthetic oils for maintaining the operational capability of exposed machinery reduction gears in cold climates. Heaters are presently used to maintain operational temperatures for lubricating oil used for

reduction gears exposed to cold temperatures. Maintenance of these heaters is a problem, in addition to their being high users of energy. It is proposed that a study be conducted to determine the effectiveness of replacing the heaters with synthetic oils that are designed to remain viscous over a wide range of temperatures. Candidate oils would be screened in the laboratory, with field tests being conducted on those oils that show good potential for success. The use of oils in place of heaters would result in reduced maintenance costs, more reliable operational capability, and a reduction in energy consumption.

Funding levels are ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
			100			100

Work Unit 5: Energy Management and Control Systems for Corrosion Inhibiting Equipment

The objective of this work unit is to develop procedures and modify controls to reduce energy consumption for corrosion inhibiting equipment in motor enclosures, operating rooms, high-voltage AC, etc. Operating procedures presently being used for corrosion inhibiting equipment and high-voltage AC will be studied and evaluated at several different installations. The information will be used to determine the optimal operating procedures for reducing energy consumption. Guidelines recommending type and use of automatic control systems will be provided. This research will utilize previous studies on energy management and control systems for high-voltage AC done for the Directorate of Military Programs and presently being utilized at Army installations. This study will result in improved utilization of corrosion inhibiting equipment, with attendant lower costs and reduced energy consumption.

Levels of funding are ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
		50	50			100

Work Unit 6: Development of Procedures for Using Vibration as a Maintenance Tool

The objective of this work unit is to record vibration patterns for mechanical equipment. When equipment wears, the vibration pattern will change. These vibration changes can be used to predict equipment failures or maintenance needs. The approach will be to determine the state of the art for this procedure. Equipment that is available will be evaluated. Equipment will be purchased, and standardized methods of testing it will be developed. Operations personnel will be trained in use of the equipment.

Funding levels are ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
			100	100	40	240

Work Unit 7: Identification of Basis for O&M Expenditures for Hydraulic Structures

The objective of this work unit is to identify the basis for O&M expenditures on flood control, navigation, and hydraulic structures and equipment and to develop uniform guidelines for prioritizing and reporting activities. District procedures will be studied to determine the basis used in the decisionmaking process regarding the expenditure of O&M funds, the collection of data regarding the projects, and the dissemination of the data associated with the expenditures. The study will include the impact on the decisionmaking activities of Corps specifications and criteria, evaluation techniques, and work prioritization procedures. Guidelines will be prepared to assist in project evaluation, prioritization, and reporting.

Funding levels are ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
				50	100	150

Work Unit 8: Control of
Roosting Birds and Bird Waste

Civil Works structures are attractive resting places for birds of all types. When there is an assembly of birds in the vicinity of operating machinery and other places frequented by personnel, the birds and bird waste become a health, safety, and nuisance problem. The objective of this work unit is to develop guidelines for detering birds from roosting on Civil Works structures. Guidance will be prepared for detering birds based upon species, type of structures, environment, and cyclical frequency. Demonstration projects will be conducted at various installations throughout the Corps.

Levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	60	60	30			150

Work Unit 9: Compatibility of
Insulating and Lubricating Oils

Insulating oils are widely used throughout the Corps for electric components of Civil Works structures. Older oils were of the acid refined type, while the newer ones are hydrogen refined. There is some question as to the compatibility of the two types. There is a similar question regarding the use of different grades of lubricating oil; e.g., in Kaplan turbines bearings. The objective of this work unit is to provide guidance on the compatibility of different types of insulating oils and of different grades of lubricating oils. Laboratory tests will be conducted and results will be provided in a manual.

Levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	60	40				100

Work Unit 10: Fire Protection
at Civil Works Structures

Civil Works structures are usually constructed of fireproof materials. However, those materials that can burn, such as cable insulation, oil, and plastic, can produce life threatening toxic fumes. Present guidance in this area is limited to that in ETL 1110-2-245, "Fire Protection: Hydraulic Power Plants," ER 1110-1-26, "Fire Protection Policy," and ER 1110-6-1, "Fire Protection and Safety." These deal primarily with the need for fire protection and the use of sensors/alarms. Additional guidance is needed for evaluating individual installations and criteria for design of adequate fire protection systems. The objective of this work unit is to prepare a procedure for evaluating the potential fire hazards at Civil Works structures and to provide design criteria for protection systems to alleviate the hazards. Guidance will be in the form of a manual.

Levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	60					60

Table CVII-1

Summary of Funding Levels

Electrical and Mechanical Research Area

Work Unit	84	85	86	87	88	89	Total
	Funding for Cited Fiscal Year, $1000's						
Task A: Corrosion Mitigation Design							
1. Corrosion-Resistant Materials for Civil Works Structures		100	100	50			250
2. Civil Works Corrosion Mitigation and Management System			100	150	100	50	400
Task Totals		100	200	200	100	50	650
Task B: Protective Coatings							
1. Painting of Submerged Surfaces			100	50			150
2. Development of High-Solids Coatings				100	50		150
Task Totals			100	150	50		300
Task C: Turbine, Generator, and Pumping Station Repairs							
1. Nondestructive Evaluation of Electrical Insulation in Rotating Machinery		100	100				200
2. Minimization of Cavitation Repair of Turbines				100	80	40	220
Task Totals		100	100	100	80	40	420
Task D: Miscellaneous Maintenance and Repair of Hydraulic Structures and Equipment							
1. Evaluation of Gate Seals and Gate Seal Heaters		40	90				130
2. Evaluation of the Use of SF_6 Circuit Breakers		50	50				100
3. Effectiveness of Cathodic Protection Systems							
4. Use of Synthetic Oils for Exposed Reduction Gears				100			100

(Continued)

Table CVII-1 (Concluded)

Work Unit	Funding for Cited Fiscal Year, $1000's 84	85	86	87	88	89	Total
5. Energy Management and Control Systems for Corrosion Inhibiting Equipment			50	50			100
6. Development of Procedures for Using Vibration as a Maintenance Tool				100	100	40	240
7. Identification of Basis for O&M Expenditures for Hydraulic Structures					50	100	150
8. Control of Roosting Birds and Bird Waste		60	60	30			150
9. Compatibility of Insulating and Lubricating Oils		60	40				100
10. Fire Protection at Civil Works Structure		60					60
Task Totals		270	290	280	150	140	1130
Area Totals		470	690	730	380	230	2500

PART VIII: ENVIRONMENTAL IMPACTS

Scope of Research

The two work units in this research area are described below. Table CVIII-1 at the end of this part summarizes the funding levels for the environmental impact research area.

Work Unit 1: Evaluation of Environmental Impacts for REMR

All REMR activities have the potential of causing adverse environmental impacts that will result in delays plus significant costs to solve the problem during or after construction. This problem can be avoided if an evaluation of the impacts of REMR activities is conducted in the early planning stages of the project. During this time, alternatives may be selected or modified to eliminate adverse environmental impacts, and meaningful decisions made concerning the selection of a specific REMR activity. Evaluation of impacts generally involves consideration of specific water quality and biological aspects of the project. Monitoring of water quality and biological parameters of specific concern is also critical in ascertaining the nature of the impact and the success of remedial actions selected. Guidance on cost-effective monitoring procedures as well as specific procedures for determining the potential for adverse environmental impacts are required to successfully evaluate REMR activities. Because of the diverse nature of REMR activities, guidance developed will have to be of sufficient generality to be applied to many activities but have the capability of being easily adapted to specific activities.

The objective of this work unit is to develop efficient procedures and guidance for evaluating the environmental impacts of REMR activities and associated monitoring requirements. All research within the work unit will take maximum advantage of completed and ongoing environmental research to incorporate these results and apply them specifically to

problems associated with REMR activities. This approach will minimize duplication and ensure that the most recent findings of related environmental research are applied to REMR activities. Within the minimum program, intensive coordination between other areas of REMR research and environmental considerations will occur to identify potential problem areas, provide specific guidance, and develop evaluation and monitoring procedures. Because of this diversity, it will be necessary to provide an equally wide availability of expertise to solve specific problems as they arise.

Within the work unit, the modification of monitoring techniques, water quality modeling, and procedures to determine the toxicity of material have been identified as specific research requirements. Monitoring procedures for specific REMR activities will be developed that identify specific water quality or biological variables of concern, sampling location and frequency, analytical techniques, and data analysis methods. These procedures will be designed to minimize monitoring requirements, providing cost-effectiveness and meaningful information consistent with specific REMR activities. Water quality models adopted for use within REMR may range from simple regression equations to numerical models, depending on the need and nature of the REMR activity. Modeling work will be closely tied to monitoring requirements since existing conditions will be used for calibration and post-construction monitoring can be used to verify model results. Modeling efforts will be short-term and near-field during construction and will be used to evaluate short- and long-term effects after construction. Because long-term simulation may be costly, models will be tailored to specific REMR activities to minimize the number of variables that must be considered in a long-term simulation. It is anticipated that some developmental work may be required to determine specific rate coefficients or modify existing algorithms to meet evaluation requirements for specific REMR activities. The scope of this work will be heavily dependent on development of REMR procedures from research in other areas of the program. As models are applied, confidence will increase and verification requirements will decrease as model sensitivity is established for different

REMR activities, regions, and environmental conditions. A wide variety of materials may be used for REMR activities that generally have unknown toxicity effects depending on the conditions under which they are used. A survey of these materials and their properties will be conducted as they are developed under other research areas to identify those materials requiring toxicity screening. Bioassay procedures (aquatic, wetland, and terrestrial) and leaching tests under a broad range of environmental conditions will be used to identify materials of potential concern. Testing will be concentrated on priority pollutants that are biologically available. If materials are identified that may result in significant adverse impacts, methods will be suggested to reduce impacts (i.e., isolate the material) or point to the need to develop alternative materials that can be safely used for a REMR activity.

Evaluation procedures developed under this work unit will allow REMR activities to be screened for potential adverse environmental impacts. Application of these procedures early in a project will permit selection of alternatives that will minimize adverse impacts, reducing project delays and costly modifications or additional construction to solve environmental problems.

The levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	200	200	200	200	100	900

Work Unit 2: Techniques to Reduce Environmental Impacts for REMR

REMR activities that have adverse environmental impacts require techniques for project restoration, incorporation of environmental features, or alternate designs to reduce or eliminate these impacts. If these techniques are not available, they cannot be integrated into project activities, and the result will be diminished project acceptability, delays, and increased costs due to additional construction or project modification to solve environmental problems. Presently, adverse impacts due to some REMR activities are known, but techniques to eliminate these

impacts are not available. In other cases, impacts are unknown and must be determined prior to the development of corrective actions. Principal impacts of concern are degradation of water quality and alteration or elimination of critical habitats or other important environmental resources. Corrective procedures are necessary to give designers maximum flexibility in selecting REMR techniques that minimize adverse impacts.

The objective of this work unit is to develop techniques for restoration, maintenance, and alternative design or construction that are cost-effective and minimize adverse impacts of REMR activities. Development of techniques to reduce adverse environmental impacts of REMR activities will take maximum advantage of ongoing or completed research in the environmental quality area, especially from the Environmental Impact Research Program (EIRP) and the Environmental and Water Quality Operational Studies (EWQOS) Program. It will be necessary to have close coordination with other research within the REMR Program to ensure that technique development is done in a timely manner and can be easily integrated or used in conjunction with REMR activites without compromising project objectives. Research within this work unit will include restoration and maintenance techniques, and alternative design or construction procedures.

Restoration techniques will include replacement or enhancement of fish and wildlife habitat, vegetation techniques to reduce erosion or reclaim problem soils, and non-vegetative methods to improve or reclaim terrestrial habitat. Guidance will be developed for specific REMR activities to restore fish and wildlife habitat to offset resource loss and mitigation requirements. Revegetation techniques will be developed to reduce erosion and water quality degradation due to construction activities. This effort will include landscaping procedures to improve project asthetics, use of vegetation to improve or manage problem soils (i.e., acid, calcareous, etc.), and development of techniques to minimize maintenance requirements for vegetation and implanting/establishment guidance for a variety of environmental conditions. Complimentary non-vegetative techniques will also be developed to reclaim or stabilize soils where vegetative techniques are not appropriate. Techniques will also include

the use of vegetation as an alternative REMR activity instead of more conventional approaches, specifically for erosion control.

Maintenance techniques that accomplish REMR and environmental objectives simultaneously are particularly appropriate to navigation projects. These will include long-term management strategies for river systems that include specific quantities and distribution of habitats as well as more traditional resource development. This guidance can be based in part on previous research on habitat values, distributions and functions, and the impacts of various project features. Specific goals for habitat quantity and distribution could be attained by the use of selective maintenance for preserving backwater habitats. These approaches will be evaluated in terms of more conventional techniques, cost-effectiveness, and ability to meet the objectives of the REMR activity.

Incorporation of environmental features through alternative design and/or construction procedures into specific REMR activities is a very attractive way to achieve environmental objectives. By examination of specific activities and evaluation of potential adverse impacts and project objectives, guidelines can be developed to reduce adverse impacts that are integral to the REMR activity. Specific examples may include borrow pit design for levee projects or construction techniques to minimize riparian habitat damage for flood control channels. Work will include evaluation at specific projects where the opportunity exists to verify the techniques and as a basis for further improvement. This evaluation will also include consideration of the costs and benefits associated with design or construction alternatives proposed.

Techniques to reduce environmental impacts for REMR activities will increase project acceptability, maintain or enhance environmental resources, and reduce delays or costs associated with corrective actions to meet environmental objectives. Incorporation of these techniques within project guidance documents for REMR activites will significantly increase the flexibility and efficiency with which environmental objectives can be achieved.

Funding levels are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
		200	200	200		600

Table CVIII-1

Summary of Funding Levels

Environmental Impacts Research Area

Work Unit	Funding for Cited Fiscal Year, $1000's						
	84	85	86	87	88	89	Total
1. Evaluation of Environmental Impacts for REMR		200	200	200	200	100	900
2. Techniques to Reduce Environmental Impacts for REMR			200	200	200		600
Area Totals		200	400	400	400	100	1500

PART IX: OPERATIONS MANAGEMENT

Scope of Research

As one phase of the REMR Research Program, it is being proposed that a computer-aided management system be developed to assist in the management of the program. This proposed system has been titled the REMR Program Management System (REPMS) and will consist of the following:

- a. Uniform evaluation procedures that will provide for consistent and uniform evaluation of the present condition of structures and equipment with a resulting condition index that will assist in prioritizing the work.
- b. Guidelines for determining the most viable maintenance and repair procedures from among various alternatives.
- c. Automated procedures for performing economic and life cycle cost analysis of maintenance and repair alternatives.
- d. An automated data base management system for storing and retrieving information and to assist in technology transfer.

Expertise from all of the R&D Laboratories will be utilized in the development of uniform evaluation procedures that will ultimately be used for prioritizing the work. This would be the critical and most important effort, and would be initiated in advance of any rehabilitation efforts. The development of an economic package, repair guidelines and consequence models, and the data base management system would proceed concurrently, utilizing expertise from within and without the Corps, as required. Table CIX-1 summarizes the funding levels.

Work Unit 1: Development of Uniform Evaluation Procedures/Conditions Index for Deteriorated Structures and Equipment

The objective of this work unit is to provide procedures that will allow consistent and uniform evaluation of the present condition of structures and equipment throughout the Corps, with a resulting condition index that will aid in prioritizing the work. Existing evaluation procedures will be utilized and new areas developed where required. A

distress indexing procedure will be established based upon the collective judgment of engineers. The determination of the condition index and prioritization of the work will be automated. Uniform evaluation procedures will all decisionmakers to prioritize the rehabilitation work and dispense funds in the order of need.

The levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	300	200	200			700

Work Unit 2: Preparation of Maintenance and Repair Guidelines with Consequence Models

The objective of this work unit is to provide guidelines for determining the most viable maintenance and repair procedures from among various alternatives. Guidelines based upon the condition evaluation index will be developed to determine feasible maintenance and repair alternatives. The guidelines will take into consideration characteristics such as the state of deterioration, load capacity, age, previous maintenance, etc. Automated procedures for evaluating and comparing various maintenance and repair alternatives will be developed. These will include the development models that will assist in determining the consequences of "repair" or "not repair" and of selecting one repair process over another. This work will provide automated procedures to assist managers in achieving better utilization of resources.

Levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
50	100	100				250

Work Unit 3: Development of Automated Procedures for Economic Analysis and Life Cycle Costing

The objective of this work unit is to develop automated procedures for performing life cycle cost analysis on maintenance and repair alternatives. An interactive life cycle costing program will be developed that will permit automated economic analysis of maintenance and repair alternatives. Factors to be incorporated into the program will include initial cost, future maintenance and repair costs, interest and inflation rates, analysis period, and salvage value. The program will provide an automated system to assist maangers in comparing the economic aspects of various maintenance and repair alternatives.

Funding levels are ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	100	100				200

Work Unit 4: *Development of Computerized* Data Management Procedures

The objective of this work unit is to develop an automated system for storing and retrieving information. An automated data storage and retrieval system for the REMR Research Program that is capable of operation from desk-sized computer terminals will be developed. Capability will also be developed for data to be added, changed, or deleted through a card reader or interactively. A report generation feature will be included. All Corps offices involved in REMR activities will have access to the same data base, thus preventing costly duplication and providing a viable path for technology transfer.

Levels of funding are ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
	100	50				150

Work Unit 5: Implementation of the REMR Management System

The objective of this work unit is to provide guidance to OCE and the districts in the implementation of the REMR Management System. This will include pilot testing, development of training manuals and courses, conducting training classes and workshops, and providing consulting services to the users. A system for obtaining and assessing feedback will be provided. "Lessons Learned" will be communicated to the users on a regular basis.

Levels of funding are as follows ($1000's):

FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	Total
50	100	100	200	250	200	900

Table CIX-1

Summary of Funding Levels

Operations Management Research Area

Work Unit	Funding for Cited Fiscal Year, $1000's						
	84	85	86	87	88	89	Total
1. Development of Uniform Evaluation Procedures/ Conditions Index for Deteriorated Structures and Equipment		300	200	200			700
2. Preparation of Maintenance and Repair Guidelines with Consequence Models	50	100	100				250
3. Development of Automated Procedures for Economic Analysis and Life Cycle Costing		100	100				200
4. Development of Computerized Data Management Procedures		100	50				150
5. Implementation of the REMR Management System	50	100	100	200	250	200	900
Area Totals	100	700	550	400	250	200	2200

SECTION D

TECHNOLOGY TRANSFER

PART I: APPROACH TO TECHNOLOGY TRANSFER

A primary concern in initiating a research program of the scope of REMR is how well the technology developed during the program will be transferred to the users. No matter how significant the findings may be, they will be of little use unless they are transmitted to and then properly applied by the appropriate individuals.

Although it is anticipated that there will be numerous users of the technology developed under the REMR Research Program, technology transfer efforts will be focused on two main groups: the O&M personnel at the various project sites, and the engineering professionals at the District and Division levels. Materials produced for communicating with these two groups will be presented in forms and at comprehension levels appropriate to the two groups.

For the project personnel, the emphasis will be on identification and evaluation of existing problems as well as on routine maintenance and repair techniques and materials. Guidance will be furnished to help them identify those problems which may require professional engineering evaluation before any corrective action is undertaken. For those problems which do not require engineering evaluation and which can be addressed by project personnel, lists of approved materials and step-by-step repair procedures will be developed.

For the engineering professionals at the District and Division levels, the emphasis will be upon providing guidance for major repair and rehabilitation activities. Generally, this information will be provided through established channels; i.e., by issuing and/or modifying EM's, ETL's, etc.

A continuing effort will be required to ensure timely transmission of the research results to the various users. This effort will involve at a minimum one full-time information specialist capable of directing the conversion of the results to the appropriate form (field notebook, film strip, formal report, letter report, etc.) and level (project personnel or engineering professional).

Finally, each of the research areas addressed by the REMR Research

Program will be overseen by a responsible OCE Technical Monitor who will have authority to implement new policy or revise existing Corps policy regarding technical matters in a given research area. Coordination between the Technical Monitors and the research Project Leaders will ensure the timely transfer to the users, in the most appropriate form, of signficant research findings.

PART II: TECHNOLOGY TRANSFER PLAN

A large amount of information already exists relating to REMR activities for Civil Works projects. This information is a result of both research and field experience gained in day-to-day work. Unfortunately, this information is mostly fragmented, scattered, and unevaluated. Because there is no systematic means for bringing such useful information together and making it available to Corps personnel, full advantage is frequently not taken of what has been previously learned in seeking solutions to current problems. Consequently, costly research findings go unused, valuable experience is overlooked, and due consideration is not given to recommended practices for solving or alleviating problems.

To correct this situation, a continuing effort to search out and synthesize useful knowledge from all possible sources should be initiated. Current practices that address specific problems selected from the various REMR research areas should be documented. Syntheses from this endeavor would constitute a series of compendiums of the best knowledge on those measures found to be the most successful in solving specific REMR problems or sets of closely related problems. As such, these would be immediately useful documents describing practices acceptable within the limitations of the knowledge available at the time of preparation. As the state of the art advances, practices can be expected to be revised and added. The synthesis documents could be easily updated by publishing related syntheses in indexed loose-leaf binders to allow insertion of new and/or revised material as it becomes available.

In addition to providing efficient transfer of technology to the field, syntheses should prevent duplication of effort by field offices and unnecessary research. Also, such a review of existing information would identify shortfalls in current technology and form a basis for planning additional research where necessary to supplement existing knowledge.

As information is developed from all sources (review of existing work, research, feedback from maintenance and repair operations, etc.), it should be directed to a central clearinghouse for analysis and

evaluation. To aid in information retrieval and analysis, a computerized data base for repair and maintenance should be established.

A major shortcoming which frequently developes during execution of a research program is that of failure to immediately transmit useable information as it is generated and before a particular phase of research is completed. In order to overcome this shortcoming and others, the following actions will be taken during execution of the REMR Research Program:

a. A clearinghouse for REMR-related information will be established during FY 1983. As information is obtained, fact sheets will be written, reviewed and approved by the responsible OCE Technical Monitor, and distributed to potential users for insertion in a previously furnished loose-leaf REMR Notebook.

b. All potential users will be provided the name and telephone number of principal and alternate research staff members associated with each research area so that the latest technology can be obtained by telephone.

c. A REMR Technology Information Exchange Bulletin will be published and distributed to users. This bulletin will be prepared on an unscheduled basis as articles become available from either researchers or, preferably, field professionals explaining how particular problems are being addressed.

d. For each research area, a research review team comprised of user representatives, the OCE Technical Monitor, the research Problem Area Leader, and representatives from other Federal agencies will be established to extract significant findings for implementation and to prevent the researchers from spending excessive time and/or resources performing work which would not be useful to the user.

e. During the research process, and as particular phases have been completed and definite procedures recommended and approved by OCE, video tapes, film strips, slide presentations, etc., will be produced and furnished to the field offices for training of users. These visual training aids will depict correct procedures, techniques, and materials being used to correct deficiencies or to evaluate the condition of a project.

f. A REMR index system will be developed so that users can rapidly locate reference materials by use of a key word system. The reference material may describe the procedure, technique, or materials needed to correct an existing deficiency.

g. Ultimately, Repair and Maintenance manuals will be prepared containing possible solutions to problems associated with each of the seven research areas. In like manner, manuals will be prepared on Evaluation Techniques and on Rehabilitation Systems.

h. In cooperation with Huntsville Division, workshops and training in the area of REMR will be established on an annual basis. This training is planned to be divided in such a way that basic maintenance and repair courses would be attended by project personnel and the repair and rehabilitation courses by designers and representatives of the Construction-Operations Divisions.

APPENDICES

APPENDIX A: SYNOPSIS OF REMR WORKSHOP,

4-5 AUGUST 1981, ARLINGTON, VA.

DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
WASHINGTON, D.C. 20314

REPLY TO
ATTENTION OF:

DAEN-CWE-DC 19 August 1981

SUBJECT: Repair, Evaluation, Maintenance and Rehabilitation (REMR) of Civil Works Projects (reference DAEN-CWE-DC, 22 July 1981).

SEE DISTRIBUTION

1. The REMR workshop was held on 4 and 5 August 1981 at the Key Bridge Marriott Hotel in Arlington, Virginia. The attendance list and agenda are attached, (Incl 1 and 2).

2. Each Division provided a presentation of its problems related to repair and maintenance of its projects. The presentations were followed by work group sessions which included each attendee and were conducted to gain maximum input from the field personnel. In this way, many of the problems related to repair, evaluation, maintenance and rehabilitation were noted. As a second step, the work groups made a first attempt at prioritizing the problems. The results of these work group sessions are attached in the form in which they were gathered, (Incl 3).

3. The findings of the work groups were summarized for the combined attendees and Mr. Lloyd Duscha, Chief, Engineering Division, Directorate of Civil Works; Mr. Bill Godwin, Acting Chief, Construction-Operations Division, Directorate of Civil Works and Mr. Jesse Pfeiffer, Directorate of Research and Development. Messrs. Duscha, Godwin and Pfeiffer each commented on the reports of the work group and comments were provided by several of the participants from the floor.

4. One of the key problems identified by the work group participants was the lack of technology transfer between organizations that have completed repair or rehabilitation projects, as well as the conveyance of research results to field offices. Any attempt to increase our effectiveness in the repair, evaluation, maintenance and rehabilitation of civil works structures will need to be based on more effective technology transfer methods, although there was a consensus among the participants that the technology transfer methods chosen should not increase the reporting burden of the districts.

DAEN-CWE-DC 19 August 1981

SUBJECT: Repair, Evaluation, Maintenance and Rehabilitation (REMR) of Civil Works Projects (reference DAEN-CWE-DC, 22 July 1981).

5. The REMR problems listed during the workshop will be further reduced to lists of those which may be solved by research, and those which reflect information needs. Mission problem statements will be prepared for those problems determined to be of the highest priority which may be solved by research.

6. A proposal for development of a REMR R&D program with target dates is attached, (Incl 4). Division comments will be sought in step 3 and a Field Review Group is to be formed by 1 December 1981. Close coordination between OCE and the divisions will continue to be an important factor of this program to promote prompt recognition of problems and effective technology transfer.

7. Your participation in the REMR workshop is appreciated.

FOR THE COMMANDER:

4 Incl
as

LLOYD A. DUSCHA, P.E.
Chief, Engineering Division
Directorate of Civil Works

C. G. GOAD
Chief, Construction-Operations Division
Directorate of Civil Works

CF:
All Workshop Attendees

DISTRIBUTION:

CDR USACED, Lower Mississippi Valley (LMVED)
CDR USACED, Missouri River (MRDED)
CDR USACED, New England (NEDED)
CDR USACED, North Atlantic (NADEN)
CDR USACED, North Central (NCDED)
CDR USACED, North Pacific (NPDEN)
CDR USACED, Ohio River (ORDED)
CDR USACED, Pacific Ocean (PODED)
CDR USACED, South Atlantic (SADEN)
CDR USACED, South Pacific (SPDED)
CDR USACED, Southwestern (SWDED)

REMR WORKSHOP ATTENDANCE

NAD	Nate Kane - NADCD Tom Bevacqua - NADEN
NCD	Lee Hoglind - NCDEN Carl Cable - NCDCO
LMVD	Cliff Boyd - LMVDEN Larry Rabelais - LMVDCO
SAD	Cecil Goad - SADCO Richard Connel - SADEN
NED	Bill Lawless - NEDEN Bernard Manor - NEDOD
POD	Kisuk Cheung - PODEN
ORD	Bill Eicher - ORDCO Griff Ray
MRD	Jim Shanks - MRDCO Dick Herse
SPD	Robert Young (from SPL but representing SPDCO) Walter Day - SPDEN
SWD	George Johnson - SWDCO Chester Berryhill - SWDEN-TE
NPD	Gene McCoy - NPDEN-GS Al Hoadley - NPD (HEDB) John Oliver - NPDEN-H
WES	Fred Brown - WES John Scanlon - WESS Leroy McAnear - WESG Frank Herrmann - WESH
CERL	Gil Williamson
CERC	Richard Weggel
CRREL	Al Wouri
OCE	BG F. T. Gay, DAEN-CWZ-B Lloyd Duscha, DAEN-CWE Bill Godwin, DAEN-CWO

(Continued)

INCL 1

AD-A125 998 REMR (REPAIR EVALUATION MAINTENANCE AND REHABILITATION) 4/4
RESEARCH PROGRAM DEVELOPMENT REPORT(U) ARMY ENGINEER
WATERWAYS EXPERIMENT STATION VICKSBURG MS
UNCLASSIFIED J M SCANLON ET AL. FEB 83 F/G 13/2 NL

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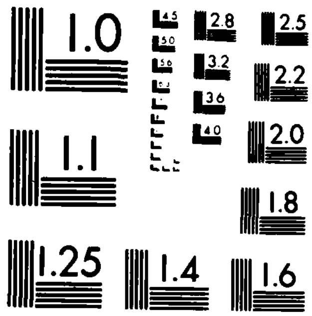

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

OCE Robert Philleo, DAEN-CWE-D
Jesse Pfeiffer, DAEN-RDC
COL Brian Branagan, DAEN-CWO
Fred Anderson, DAEN-CWE-DC
Dr. Tony Liu, DAEN-CWE-DC
John Mikel, DAEN-CWO
Bruce McCartney, DAEN-CWE-HD
Keith Snyder, DAEN-CWE-E
Nancy Tessaro, DAEN-CWO-R
Paul Fisher, DAEN-CWE-SG
Don Barnes, DAEN-CWR-W
Lucian Guthrie, DAEN-CWE-DS
Jim Gottesman, DAEN-CWO-M
Tom Rosato, DAEN-CW
Kathy King, DAEN-CWO
Roger Rodriques, DAEN-CW
MAJ R. B. Ottesen, DAEN-RDC

Workgroups: 8:00-10:00 am, 5 August 1981

GROUP 1

John Mikel
Nate Kane
Carl Cable
Cecil Goad
Bernard Manor
Griff Ray
Robert Young
Chester Berryhill
John Oliver

GROUP 2

Jesse Pfeiffer
Tom Bevacqua
Cliff Boyd
Richard Connell
Kisuk Cheung
Jim Shanks
Walter Day
Gene McCoy

GROUP 3

Bruce McCartney
Lee Hoglind
Larry Rabelais
Bill Lawless
Bill Eicher
Dick Herse
George Johnson
Al Hoadley

GROUP 4

COL Branagan
Fred Brown
John Scanlon
Leroy McAnear
Frank Herrman
Gil Williamson
Richard Weggel
Al Wouri

AGENDA

Date: 4-5 August 1981
Location: Key Bridge Marriott Hotel, Arlington (Rosslyn) Virginia.

<u>3 August</u> Travel Day

<u>4 August</u> Moderator: Robert E. Philleo
Chief, Structural Br., Engr. Div.
Directorate of Civil Works

1.	Introduction Brig. General F. T. Gay Deputy Director Directorate of Civil Works Lloyd A. Duscha Chief, Engineering Div. Directorate of Civil Works Bill C. Godwin Actg. Chief, Construction-Operations Div. Directorate of Civil Works	8:00 am - 9:00 am
2.	Division Presentations NAD NED	9:00 am - 9:40
	BREAK	9:40 am - 10:00
	Division Presentations SAD MRD NCD ORD NPD	10:00 am - 11:45
	LUNCH	11:45 am - 1:00 pm

INCL 2

Division Presentations	1:00 pm - 2:30
SPD	
POD	
LMVD	
SWD	
BREAK	2:30 pm - 3:00
3. Lab Reviews of Accomplishments in this Field	3:00 pm - 4:00

John Scanlon, WES
Gil Williamson, CERL
Richard Weggel, CERC
Al Wouri, CRREL

5 August

4. Workgroup Discussions of Problems/ Prioritization of Problems	8:00 am - 10:00

Group 1.	Group 2.	Group 3.	Group 4.
John Mikel	Jesse Pfeiffer	Bruce McCartney	COL Branagan

BREAK	10:00 am - 10:30
5. Summarization of Workgroup Findings	10:30 am - 11:00
6. Discussion of Appropriate Response by OCE and Labs.	11:00 am - 11:45

Lloyd Duscha
Bill Godwin
Jesse Pfeiffer

7. Closing Remarks and Adjourn

REMR PROBLEMS/NEEDS

GROUP 1

PRIORITY I

High velocity channel design/repairs

Improved instrumentation/evaluation of structures.

Improved corrosion resistance techniques.

Improved technology transfer

Improved underwater repair techniques

Improved sedimentation elimination techniques

Vessel Impact barriers at locks

Improved techniques to evaluate when to repair (remaining life/life cycle analysis)

Improved rubble mound jetty/breakwater repair/design methods

Improved bank stabiltiy repair techniques

Improved concrete crack repair techniques

Improved vessel channel dimension requirement analysis techniques

Improved downstream slope protection for overtopping problems

PRIORITY II AND III

Lock speed up

Roof techniques

Cavitation protection

Vandal-proof designs

Incl 3

Project security

Schedule maintenance

Bulkhead/sheet pile repair

Jetty inspection

Concrete impact tests

Energy conservation impacts

Dewater dredge material

Ice management in locks

Evaluation of capacity of recreation areas.

Switch gear probelms

Lock gate fenders

Non-structural alternatives

Hydrosurveys

Beach breach closure techniques

Improved materials

Restroom design

User safety considerations

Herbicides

Improve debris basin design

Economics of/for repairs

Slope stabilization

High water dewater techniques

Concrete repair

Quoin block backing materials

Permafrost degradation

Seepage problems

Road repairs

Supply procurement problems

Timber pile repair

Turbine repair

Test/monitor techniques

Design procedures

Concrete evaluation techniques

Brick repair

Gate hoists

Dispersive clays

Pump station repair

Bridge repairs

Lock filling/emptying problems

Fixed sand-bypass

Design of concrete/soil anchors

Design improvements

Earth dam filter drains

Ice damage to breakwater

Construction for life cycles

Trash accumulation

Lock fleeting design

Slant axis shaft fatigue

Embankment seepage control

Manpower problems

Relief well design/installation

Waterstop repair

Stilling basin repair

Structure/foundation evaluation and monitoring

User fee impacts R&D management

Funding for repair and maintenance

Dredge material dewater methods

Stream bed scour prevention

Timing of repair/maintenance

Generator Winds

Inlet hydrodynamics

GROUP 2

PRIORITY I

Estuary sediments

Flat roofs

Underwater repair

Joint sealants

Cracked sealants

Repair of old concrete

Stilling basin erosion

Underwater survey techniques

Electric insulation evaluation

Maintenance of existing anchors

Embankment seepage

Boulders to stabliize waves

Structure movement evaluation

Structure movement measurement

Equipment service life evaluation

Non-destructive testing

Concrete testing (old concrete)

Cathodic protection

Improved evaluation of old structures

Improved seismic evaluation of old structures

Lock control modernization

Dredge material measurement

Repair blockage internal drains

Instrumentation for old dams (aging process)

Automated data handling for instrumentation

PRIORITY II

Corrosion

Fly ash uses (soil, concrete)

Anchor unstable structures

Rip-rap failure

Rip-rap sizing

Generator repair

Riverbank erosion control

Deck wearing surfaces

Underwater coatings

Waterstop repairs

Backing materials for mitre gates

Dewatering of dredged materials

Wood piling protection

Blasting old concrete

Underwater installation of bulkheads

Rehab of jetties

Jetties that leak sand

Dam safety inpsection procedures

Methods for handling trash

Waterflow measurement in penstocks

Instrumentation

Anchorage repair/design

Liquefaction of embankment materials

Dewatering of structures

Levees on poor foundations

Cavitation on metal control gates

Improved lock operations

Improved relief wells in cold regions

Underdrain replacement

Deform characteristics of foundations

Foundation (expansive soil) design/repair

PRIORITY III

Diversion of lava flow

Ice operational problems

Structures in and on dikes

Berms or relief wells

Structures on permafrost

Paint for gates

High water lock closures

Location and quality of acquifers

Use of salt water for concrete

Downstream encroachment control

Green-heart timber

Explosive excavation for dredging

Determine source of sand (S. California)

Usage of wet soil in dams

Ice damage to control gates

Standard motors for spillway gates

Low maintenance vegetation

Eventual location of dredged materials (San Francisco Bay)

Life expectation of corroded steel structures

Repairs during traffic

Road rehab practices

Submarine cable

Sand bypassing

Mooring facilities

Stilling basin siltation pronlems

Stilling basin erosion problems

GROUP 3

PRIORITY I

Underwater concrete repairs

Ice problems

Lubrication

Predict mechanical failure

Slant turbines

Feedback on rehab performance

Technology transfer

Roof repair

Turbine cavitation

Paint

Underwater repair

Guide specs and regulations improvement

Underwater inspections

Generator windings

Corrosion

Generator breaks

Contracting O&M

Concrete repair techniques

PRIORITY II

Gate seals

Roads rehab

Emergency generators improvements

Clay

Hoist machinery

Oil discharge

Riprap

Concrete erosion

Generator breakers

Optimum navigation channel depth

Soft bank erosion

Waterstops

Tow haulage units

Improve management on lock down-time

Dredge disposal

Lock wall rehab

Turbine improvement

Hydraulic gate cavitation

Waterproof bridge decks

Lock gates

Piezometer replacement

Fire protection

Seepage

New geotechnical monitoring & instrumentation

Joint repairs

Rock anchors (concrete)

Fish kills

Breakwater repair

Beach nourishment

Debris control and removal

Accurate surveys

Remote project operation and maintenance

Inspection, maintenance of local protect projects

Pump station repairs

PRIORITY III

Vegetation control

Vandalism

Mooring facilities

Sanitary waste disposal

Rock channel slope protection

Floating mooring bits

Recreation facility flooding

Lock filling system

Brick repair

Lock chambers for floodways

Operation of air screens

Relief wells

Wind blown sand

Restroom rehab

GROUP 4

PRIORITY I

Underwater repairs

Underwater inspections

When to repair?

Structural instrumentation

Removal of damaged concrete

Modernize mechanical/electrical

Cathodic protection

Design criteria update

Generator rewind & testing

Stilling basin erosion

Sheet pile corrosion

Hydrographic survey techniques

Concrete repair

Uncontrolled seepage

Rip-rap repair (techniques & materials)

Scour of channels

Minimize dredging

Sand bypassing

Ice prevention

Probability of failure

Non-destructive testing

Sediment budget study

Subsurface exploration

Economy of repair alternatives

Technology transfer

Precast form use

Evaluation of corrosion on structures

Remote monitoring

Optimum depth/alignment of channels

Influence of aging on materials

Data collection/analysis

Evaluation of maintenance records & trend

Resurface lock walls

Crack repair

Underwater painting

Vertical datum - hydrographic surveys

Control of debris in stilling basins

PRIORITY II

Shotcrete evaluation

Standard gate hoist motors

Joint seals

Grouting

Training maintenance personnel

Gate seals

Reinforced doloes

Monitor waves and current

Alkali aggregate reaction

Evaluation of proprietary materials

Breakwater toe protection

Rock bolts

Alternatives to cut-offs (seepage)

Scheduled lockages

Assess life cycles

Soil stabilization

Reline tunnels and conduits

Defining service contracts

Training dike repairs

Jetty/breakwater repair

Improved coating of hydro structures

Aggregate quality control

Roof repair

O&M cost efficiency

Performance monitoring

Soil sand erosion

Vegetation problems

Cold weather patching

Freeze/thaw

Environmental effects

Locks traffic management

Cavitation

Armor unit reinforcement

Impermeable jetties

Vibration effects & solutions

Rapid-set patching

Liquefaction (foundation)

Reservoir slope stablization

Vandalism

Winter construction

Leaky water stops

Contracting problems

REMR management

Cracked embankment

Dewater procedures

PRIORITY III

Relief well construction

Cause of sinkholes

Rehab drain system

Water penetration of brick

Lightweight concrete

Effect of water levels on slope stabilization

Bridge deck repair

Soil compaction/heavy compaction

Protect earth dams from overtop

Preventative maintenance

Pavement recycling

Detection system on embankments

Pump repair

Flood proofing recreation facilities

Repair of timber pilings

Soil-foundation reinforcement

Herbicides

Local maintenance

Pavement repair

Dredging criteria

Tow-impact on mitre

Public perception

Control vegetation on rip-rap

New materials

Materials for shore protection

Mooring facilities

Rehab of rest rooms

Vegetation for scour

Technology Transfer

PRIORITY I

Audit/enventory

Lab write up of field accomplishment

Conferences/workshop

Video tape

Centralized clearing house

Review similar problems in military constructions

ETL's

Steering committee

Survey of industry/other organizations

Center of competence (Focus)

Executive summary

Feedback (input)

Newsletters

Lab Review (visit) Field method

Review Existing methods

INDEX System

PRIORITY II

Computer/Abstracts (Data base)

Training courses

Identify experts

Slide tapes

Lab team to Divisions/Districts

One-stop services

Articles in "Engineering Update"

Manual on REMR

Engineering pamphlets

PRIORITY III

Films

ER's

Technical reports

REMR Research Ideas and Possible Solutions
(Not Prioritized)

GROUP 1

Increased use of standard designs/sizes (avoid unique designs)

Streamline R&D contracts

Improve inventory of spare parts

Non-dredge alternatives to breach closure

More repair funds

Take funds from construction-general

Increase energy conservation awareness

Review non-Corps maintenance specs

Quick tech transfer

Mandatory life cycle analysis prior to construction

Improve value engineering review process

Mobile repair teams

Increase funds for tech transfer

Improve designs

Lock traffic real time vessel info/control system

Increase maintenance manpower

Improve manpower allocation management system

Upgrade operations personnel

Remove supply, procurement restrictions

Increase R&D funding

Simplify A-76 procedures

Dredge material dewater method

Separate F&D funding from project funding

Operability/User review during design/construction

New sources of R&D

Consolidate all R&D laboratories to improve management (eliminate duplication and competition for work)

Review of current REMR information/guidance (other than Corps')

Review/evaluate existing specifications

GROUP 2

Underwater survey techniques

Methods of lock operations

Cut-off wall designs

High voltage insulation methods

Use of fly ash in soils

Allowable movement of structures

Improved instrumentation

NDT for generator winding

Wetland definition

Determination of underground aquifers

Flushing of sediments by natural flows

Improved waterflow measure techniques

Studies of tidal waves

Underwater repair materials

Concrete crack repair materials and methods

Materials and methods for reparing eroded concrete

Determine soundness/adequacy of existing concrete

Method of determine roof leaks

Equipment condition evaluation procedures

Concrete removal techniques

Improved foundation materials under old structures subjected to expansive soils

Reduce manpower to accomplish REMR

State-of-the-art R&D on hydrology

Methods to protect corroded sheet piles/materials

Generator repair requirements

Use of salt water in concrete

Design of old structures to allow overtopping

Technology transfer

Repair methods for underdrain systems

GROUP 3

Develop unleaded paint

Develop abrasion, corrosion resistant paint

Paint surface preparation methods

Underwater repair techniques

Reduce and combine guide specifications and regulations

Develop underwater inspection techniques (side scan sonar, submarines, divers, TV, etc.)

Develop non-destructive testing method to determine the remaining life of the generator

Use plastic to reduce corrosion

Use suitable non-asbestic material for generator breaks

Streamline O&M contracting procedures

Inventory of successful (and unsuccessful) contract items

Improve scope of work for O&M contracts

Underwater concrete repair materials

Develop ice breaking, suppression, prevention, and removal methods

Develop automatic or self lubrication methods for lock gate pintles, slant turbines, tainter gate trunions

Vibration monitoring and analysis of mechanical equipments

Use post-tensioned shaft for slant turbines

Study metal fatigue problems in slant turbines

Develop technology transfer methods

Use sloped roofs

Improved turbine design/material to reduce cavitation

GROUP 4

Evaluate environmental impacts

Aquatic plant research

Mathematical model of oprations

Construction techniques

Lab test of interlocking breakwaters

Soil additives

Gate seal design

Alternatives to paving for secondary roads

Dewater procedures or alternatives

Improve Anchors

Mechanism of corrosion

Transfer of vertical data

Scour protection

Develop abrasion resistant concrete

Data techniques for sand bypass

Procedures for tech transfer

Methods of floodproofing

Evaluation of sealers

Nonstructural techniques

Densify sand foundations

Riprap criteria

Mitre gate protection

Sediment transfer mechanism

Exotic materials

Vandal proofing

Vibration control

Side scan sonar

Underwater inspection techniques

Concrete surface rpair techniques

Hydrologic models

Techniques for condition assessment

Electro-mechanical equipment update

Concrete removal techniques (blasting, water flame, etc.)

Corrosion course for designers

Maintenance review

Computer programs for analysis

Define sediment budget

Impact of criteria changes

Commercial use of dredge material

Rehab evaluation incl economics

Non-destructive testing

Prefab wells

Geophysical tools for subsurface exploration

Roofs

Cold weather patching materials

Case studies of minimum dredge (optimize)

Conduits to prevent cavitation

Management system for REMR

Economic repair of steelpiling

Bond & anchor system

Load & stress analysis of concrete armor units

Stilling basin & baffle block design

Instrument design

Acoustic emissions

Underwater repair techniques

Thermography

Ice in locks

End stream sediment trap

Prediction of materials life cycle

Risk based analysis

Remote monitoring (for seepage, etc.)

Joint materials

Improve specifications and regulations

Lightweight concrete

Insitu foundation improvement

Standardize motors/generators

Breakwater toe protection

Asphalt repair

Wastewater treatment in recreation sites

Optimize maintenance procedures

Shotcrete as a repair material

Sink hole problems

Optimize lockage procedures

Condition evaluation procedures

Slope protection methods

Evaluate alternate cut-off walls

Obsolete equipment repair

Insure maintainability in design

Maintenance scheduling

Slope response to dewater

Insitu resistor of drains

Coating materials

Types of grasses

Industry search

Seepage control mechanism

Winter construction techniques

REMR R&D PROGRAM DEVELOPMENT

DAEN-RDC

7 August 1981

	Action	Assigned Organization	Suspense
1.	Report of meeting Provide field with raw data developed at meeting	CWE Coord: CWO RDC	19 Aug
2.	Reduce raw data; develop list of priority problems for R&D; develop list of priority problems solveable by other means (get additional input from CWE/CWO/Labs) Send to field Divisions for comment	CWE/CWO Input: RDC	30 Sept
3.	Prepare Mission Problem Statements for problems on list in 2 above	CWE/CWO	30 Nov

4.	Develop draft report on proposed REMR R&D Program
	- Background
	- Priority problems
	- Proposed R&D Program
	  - WU's
	  - Schedule
	  - Costs
	  - Tech. Transfer
	- Benefits provided
	  - $ Savings
	  - MY Savings
	  - Improved procedures
	  - Safety Improvements
	  - Etc.
		WES	1 Feb 82

5.	Brief Director, CW, on REMR	WES	15 Feb
6.	Establish Field Review Group (FRG) for REMR	CWE/CWO Coord: RDC	1 Mar
7.	Develop R&D Program Documentation for REMR	WES	1 May
8.	R&D Program Review for REMR (REMR FRG would review program)	RDC/WES/FRG Tech Monitors,	15 June
9.	Initiate REMR R&D Program	Labs (WES, REMR PROG MGR)	1 Oct 83

Incl 4

APPENDIX B: REFERENCES

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